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STUDY REPORT
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ARDENNES CAMPAIGN SIMULATION (ARCAS)

DECEMBER 1995

PREPARED BY
TACTICAL ANALYSIS DIVISION

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13. ABSTRACT (Maximum 200 words) The Ardennes Campaign Simulation (ARCAS) Study was performed to improve the credibility of the Stochastic Concepts Evaluation Model (STOCEM) simulation by comparing a STOCEM simulation of the WW II Ardennes campaign of 1944-45 with historical campaign results. Historical campaign data had been developed, from archival sources, into a computerized data base denoted as the Ardennes Campaign Simulation Data Base (ACSDB). The initial positions, configuration, strengths, compositions, and availabilities of forces for the campaign, as depicted in the ACSDB, were used to define the STOCEM force laydown for ARCAS. Simulation results (front-line movement, major system losses, and casualties) are compared with historical results from the ACSDB. Stochastic variability of average model outcomes is also quantified in terms of confidence limits and bounds. The comparison of simulation results with history is used to develop guidelines for algorithmic changes which improve model credibility of STOCEM. Insights on model verification and validation (V&V) are also developed.			
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ARDENNES CAMPAIGN SIMULATION (ARCAS)	STUDY SUMMARY CAA-SR-95-8

THE REASON FOR PERFORMING THE STUDY was to improve the credibility of the Stochastic Concepts Evaluation Model (STOCEM) simulation by comparing a STOCEM simulation of the WW II Ardennes campaign of 1944-45 with historical results of that campaign. The comparison of simulation results with history is used to assess the appropriateness of STOCEM logic and to develop guidelines for algorithmic changes which improve credibility of the STOCEM and of the related Concepts Evaluation Model IX (CEM IX). Insights on model verification and validation (V&V) are also developed.

THE STUDY SPONSOR is the Director, US Army Concepts Analysis Agency, 8120 Woodmont Avenue, Bethesda, MD 20814-2797.

THE STUDY OBJECTIVES were to:

(1) Assess the appropriateness and verisimilitude of simulation algorithms; i.e., whether the trends in the combat simulation results are similar to historical results. If so, then the appropriateness of the combat model's underlying logic gains credibility.

(2) Discover any needed changes and/or improvements in rules, algorithms, and capabilities of the combat model employed. When combat simulation results and trends differ substantively from history, reasons are sought to explain the difference.

(3) Support verification and validation (V&V) of the STOCEM simulation.

THE SCOPE OF THE STUDY was to use the STOCEM to simulate the 1944-45 Ardennes Campaign represented in the Ardennes Campaign Simulation Data Base (ACSDB). Sixteen replications of each STOCEM scenario were executed. Campaign outcome measures compared include, personnel casualties, weapon kills, ammunition expended, and forward edge of the battle area (FEBA) progress.

THE MAIN ASSUMPTIONS of this work are:

(1) The ACSDB accurately represents the World War II (WWII) Ardennes Campaign of 1944-45.

(2) Kill/casualty criteria used in CEM and in the ACSDB are comparable.

THE BASIC APPROACH was to use STOCEM to stochastically simulate the 1944-45 Ardennes campaign, to compare STOCEM simulation outcomes with historical outcomes from the ACSDB and to use these comparisons to develop credibility-enhancing model improvements as well as model validation insights for STOCEM.

THE PRINCIPAL FINDINGS of the work reported herein are as follows:

(1) Similarities in magnitude and trend between simulation and history were found in FEBA progress and tank losses during the first half of the scenario, German armored personnel carrier (APC) losses, total US/UK personnel casualties, and US/UK ammo tonnage expended.

(2) Major differences included excessively fast STOCEM FEBA movement during the last half of the campaign, excessively high antitank/mortar (AT/M) losses and US/UK APC losses, excessively low artillery losses, and a much larger German ammunition tonnage expenditure. The

STOCEM partition of casualties into killed (KIA), wounded in action (WIA), captured/ missing in action (CMIA), and disease/nonbattle injuries (DNBI) also differed from history.

(3) Analysis of differences between STOCEM and history indicated the following major logic-dependent/input-dependent causes:

(a) STOCEM shows a tendency to generate excessive movement, system losses, and personnel casualties while a large fraction of one side (force) is attacking (Logic-dependent).

(b) The historical results indicate a successful US/UK policy of conserving mechanized systems by reducing their vulnerability and exposure after D+8, but this conservation policy was not reflected in STOCEM (Logic-dependent).

(c) If the catastrophic breakthrough effects of the initial German attack, not modeled in STOCEM, are discounted, then both history and STOCEM show negligible US/UK artillery losses (Logic-dependent).

(d) Some ARCAS STOCEM inputs may need revision. The STOCEM move rates used in ARCAS are too high because they reflect a potential movement capability not generally achievable in real combat. Actual combat movement is also degraded by tactical, weather, and logistical considerations not explicitly modeled by STOCEM. Other candidate ARCAS input revisions include AT/M and artillery system vulnerabilities, and single round German ammunition weights. (Input-dependent).

(4) The primary changes to STOCEM logic/inputs suggested for investigation by the comparisons include:

(a) Modified logic to moderate move rate in response to a "sufficiently sustained" rapid combat advance and to reduce an attacker's base STOCEM lethality against enemy tanks and APCs, with a higher reduction associated with a higher strength advantage. (Logic-driven).

(b) Adding an optional "conservative use policy" reducing vulnerability of mechanized systems when favorable attack conditions have been created after heavy losses. (Logic-driven).

(c) Modification of the STOCEM casualty partitioning logic to better fit the historical data on KIA, WIA, CMIA, and DNBI. (Logic-driven).

(d) Modifying STOCEM to simulate a "breakthrough" attack posture, for a limited duration, generating accelerated defender systems attrition and CMIA/DNBI, related to speed and overwhelming force advantage. (Logic-driven).

(e) Reduced ARCAS STOCEM input values for unit move rates and for vulnerability of armor and AT/M systems. Increased input values for vulnerability of artillery. (Input-driven).

THE STUDY EFFORT was directed by Walter J. Bauman, Tactical Analysis Division, US Army Concepts Analysis Agency.

COMMENTS AND QUESTIONS may be sent to the Director, US Army Concepts Analysis Agency, ATTN: CSCA-TA, 8120 Woodmont Avenue, Bethesda, Maryland 20814-2797.

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CHAPTER 1

EXECUTIVE SUMMARY

1-1. PROBLEM. Army Regulation (AR) 5-11 prescribes policy on the verification, validation, and accreditation of Army models. Validation of a theater-level combat simulation requires the translation of a real-world campaign into detail compatible with the simulation model inputs and outputs. Lack of appropriate and comprehensive historical campaign data has limited and frustrated efforts to generate meaningful theater combat model comparisons with history. Representation of a historical campaign in a theater combat simulation requires a sufficiently complete and consistent historical data base for that campaign. Use of historical data as input to the combat simulation enables generation of a model representation of the campaign. Subsequent comparison of simulation and historical outcomes is then useful for application of the validation policy of AR 5-11 and for assessment of needed changes in combat model algorithms to better reflect combat. The Director, US Army Concepts Analysis Agency (CAA), directed that a new history data base describing the 1944-45 Ardennes Campaign of World War II (WWII) should be constructed and that the Stochastic Concepts Evaluation Model (STOCEM) should use that historical data to simulate the campaign.

1-2. BACKGROUND. In 1987, the Director, CAA, proposed that a WWII campaign be selected for representation by an operational theater combat simulation at CAA. Using historical data as input, the campaign is subsequently recreated, as closely as possible, through simulation. Simulation results can then be compared with history data and can also be used to assess needed changes and/or improvements in rules, algorithms, and capabilities of the combat model employed. In September 1987, the Historical Evaluation and Research Organization (HERO) was issued a contract to construct a comprehensive history data base of the WWII Ardennes 1944-45 campaign (popularly known as the Battle of the Bulge). This data base, designated as the Ardennes Campaign Simulation Data Base (ACSDB), was completed in December 1989 by Data Memory Systems, Incorporated. Due to competing analytic priorities and commitments in the face of constrained resources, the comparative analysis of simulation results versus history was not completed until 1995. The combat simulation used in the analysis was the Stochastic CEM (STOCEM), a stochastic version of the Concepts Evaluation Model IX.

1-3. PURPOSE AND OBJECTIVES

a. Purpose. The purpose of the Ardennes Campaign Simulation (ARCAS) Study is to determine how, where, and why patterns of simulated STOCEM combat representing the WWII Ardennes Campaign of 1944-45 are similar to, or differ from, patterns reflected in historical Ardennes campaign archives (history) recorded in a data base. Similarities between trends in STOCEM outcomes and history can provide support for model validation (of STOCEM/CEM). If a STOCEM trend differs substantively from the historical record, then, if a rationale for the historical outcome/trend and be discerned, justified, and quantified, it can become the basis for modification of STOCEM simulation logic which will improve STOCEM realism and credibility.

b. Objectives. Comparison of STOCEM combat simulation results with history data is used to:

(1) Assess the appropriateness and verisimilitude of simulation algorithms; i.e., whether the trends in the STOCEM combat simulation results are similar to historical results. If so, then the appropriateness of the combat model's underlying logic gains credibility.

(2) Discover any needed changes and/or improvements in rules, algorithms, and capabilities of the combat model employed. When STOCEM results and trends differ substantively from history, reasons are sought to explain the difference.

(3) Support verification and validation (V&V) of the STOCEM simulation.

Recommendations developed in ARCAS, although based on STOCEM applications, may also be applicable to CEM IX applications because STOCEM is just a stochastic version of the deterministic CEM IX simulation. STOCEM and CEM IX have the same scenario inputs and combat event logic.

1-4. SCOPE

a. The base campaign scenario used in the combat simulation is the 1944-45 WWII Ardennes Campaign represented in the ACSDB historical data.

b. The combat simulation used to represent the historical campaign is the STOCEM.

c. Each STOCEM scenario is executed for 16 stochastic replications. Each STOCEM result is represented as an average (arithmetic mean) over the 16 stochastic outcomes.

d. Uncertainty in STOCEM outcomes is statistically expressed in terms of confidence limits and maximum/minimum values over the 16 replications.

e. Campaign outcome measures available for comparison (STOCEM vs history) include personnel casualties, weapon system kills, ammunition consumption, and progress of the forward edge of the battle area (FEBA).

f. STOCEM is treated in this document as including processors denoted as the Combat Sample Generator (COSAGE) and the Attrition Model Using Calibrated Parameters (ATCAL).

1-5. LIMITATIONS

a. A recommendation presented herein is presented only as a possible, or probable, course of action which may be neither the best, nor the only, proposal, in light of the information presented in associated charts and graphs.

b. STOCEM simulates casualties only in line units and artillery units. Casualties and system kills in nonartillery rear echelon units are excluded from comparison.

c. STOCEM reports personnel casualties stratified into casualty types (e.g., killed in action (KIA), wounded in action (WIA)) only for the United States/United Kingdom (US/UK) force (although total casualties are generated in the same manner for both sides).

d. The 16 replications of STOCEM executions for each scenario are not sufficient to assume that the average STOCEM outcome can be based on a statistically normal sampling distribution of the mean.

e. Comparisons between STOCEM results and historical results can be meaningfully done only for theater averages over large aggregates of units and areas. The STOCEM does not have the resolution to enable comparison of low-level (unit/corps) battle and movement.

f. Human factors (e.g., fatigue, caution, aggressiveness) regulating the pace and intensity of battle were not quantifiable.

1-6. TIMEFRAME. The scenario time frame was from 16 December 1944 (denoted as D-day) through 16 January 1945.

1-7. ASSUMPTIONS

a. The Ardennes Campaign Simulation Data Base adequately represents the status and structure of forces in the actual WWII Ardennes Campaign of 1944-45.

b. A baseline historical FEBA comparable to the FEBA used in CEM can be defined by averaging locations of unit supplement locations reported in the ACSDB. Location reporting errors in the ACSDB are assumed negligible.

c. Weapon effectiveness inputs were based to the maximum extent possible on data from system and munition types employed in WWII. When lethality data on WWII munitions were unavailable, required effectiveness measures were based on comparable postwar surrogate munitions for which data were available.

d. The personnel casualty and system kill criteria used to categorize CEM results are consistent with and comparable to the casualty/kill criteria reflected in the historical data, enabling direct comparison of STOCEM casualties/kills with historic casualties/kills.

1-8. STUDY APPROACH AND METHODOLOGY

a. The basic approach employed consisted of construction of a history data base for the Ardennes Campaign, use of the data base to develop input data for the campaign representation in the combat simulation, execution of the combat simulation, comparison of simulation results with history as recorded in the history data base, and assessment of similarities and differences in these comparisons. The combat simulation used in the analysis was the STOCEM, a stochastic version of the CEM IX, which is in operational use at CAA. Therefore, ARCAS results/recommendations may also be applicable to CEM IX applications.

Stages of the methodology include the following:

(1) The input data for the Ardennes Campaign was formulated for the STOCEM using:

(a) Initial Conditions from a History Data Base. The historical data base used by ARCAS is a computerized data base designated as the Ardennes Campaign Simulation Data Base. The initial positions, configuration, strengths, compositions, and availabilities of forces for the campaign, as depicted in the ACSDB, were used to define the force laydown for STOCEM.

(b) Historical War Plans. Documentation on the intended war plan of the German forces was used to define the objectives and avenues of attack for the STOCEM force laydown. The ACSDB was used to define where the divisions and brigades were positioned at the start of combat. War plans were used to define where corps and armies were directed after combat began.

(c) Weapon System Effectiveness Data. Effectiveness parameters (e.g., range, rate of fire, lethal area/probability of kill given a hit) of weapon systems employed in the Ardennes Campaign were generated for input into a STOCEM preprocessor, based on their WWII employment conditions. Intrinsic munition effectiveness measures not available in WWII history data were determined by interpolation and/or extrapolation of test results from comparable weapons.

(d) Terrain and Processing Parameters. Maps showing topography of the campaign area were used to define and locate terrain types impacting on mobility potential. These terrain types and locations were overlaid onto the STOCEM theater representation. A number of parameters regulating model combat algorithms were also input.

(2) STOCEM produces simulated outcomes which are then compared with the actual historical outcome, as represented in the ACSDB. Every effort is made to ensure that the STOCEM measures and the associated ACSDB values reflect the same scenario conditions; i.e., they are based on the same set of units, weapon types, geography, and employment doctrine.

(3) Similarities and differences between the simulated and the historical combat trends and patterns are then described and used to:

(a) Assess STOCEM's fidelity to the historical campaign's general development.

(b) Highlight areas where improvements may be made in STOCEM logic/algorithms to better reflect "real" combat as reflected by history.

(c) Provide evidential data on STOCEM validation by assessing the degree to which STOCEM is an accurate representation of the real world from the perspective of its intended use.

1-9. SUMMARY OF FINDINGS AND OBSERVATIONS. The study directive, shown in Appendix B, specifies the following essential elements of analysis (EEA), which are presented below with a summary of the responses which resulted from the study.

a. What major similarities and differences in critical elements exist between the ARCAS STOCEM results of the Ardennes Campaign and the historical record of that battle? The key findings from the comparison of the STOCEM simulation of the Ardennes Campaign (ARCAS) with history are summarized in Table 1-1. They include:

(1) FEBA Movement. During most of the first half of the campaign, history and ARCAS show similar FEBA movement in the theater area comprising the historic "bulge." During the first 4 days and in the US/UK counteroffensive in the last half of the campaign, the ARCAS STOCEM FEBA movement is much faster than history.

(2) Ammunition Expenditure

(a) ARCAS STOCEM US/UK tonnage expended is similar to history.

(b) ARCAS STOCEM German tonnage expended is much higher than history.

(3) Weapon System Losses

(a) Cumulative ARCAS STOCEM tank losses and German armored personnel carrier (APC) losses are similar to history during the first half of the campaign.

(b) ARCAS STOCEM antitank/mortar (AT/M) losses and US/UK APC losses are much higher than history. After D+8, historical US/UK APC and AT/M losses are negligible.

(c) ARCAS STOCEM artillery losses are considerably lower than historical losses, but US/UK losses are negligible in both STOCEM and history if catastrophic breakthrough effects present in the historical campaign, but not amenable to modeling, are discounted.

(4) Personnel Losses

(a) ARCAS STOCEM cumulative total US/UK casualties are similar to history both in magnitude and trend.

(b) ARCAS STOCEM cumulative total German casualties are greater than history.

(c) The ARCAS STOCEM distribution of casualties over casualty types has too large a proportion of KIA and WIA and too low a proportion of captured, missing in action (CMIA) and disease and nonbattle injury (DNBI).

Overall, the ARCAS forces, as modeled in STOCEM tend to move faster than history and to lose both personnel and weapon systems, excepting artillery, at a somewhat faster rate than history.

Table 1-1. Summary of ARCAS vs History Comparisons

Outcome type	Similarities: ARCAS vs history	Differences: ARCAS vs history
FEBA	(1) Maximum FEBA advance (2) FEBA "bulge" configuration	Faster movement in ARCAS
Ammunition expenditure	US/UK tonnage expended	Much more German tonnage expended in ARCAS
Tank losses	Losses in first 16 days of scenario	Excessive ARCAS losses in last 16 days
APC losses	German losses	Excessive ARCAS US/UK losses
AT/M losses		Excessive ARCAS losses
Artillery losses	US/UK losses when catastrophic breakthrough effects are discounted	Considerably lower ARCAS losses
Personnel lost	(1) US/UK total casualties (2) DNBI & CMIA trends over time	(1) Excessive ARCAS total German casualties (2) Proportion of ARCAS KIA & WIA too large (3) Proportion of ARCAS CMIA and DNBI too low

b. What appear to be the causes of the differences between simulation results and those from the historical battle records?

(1) Logic-dependent

(a) Historical Logistics Circumstances Not Amenable to Modeling. The excessively large German ARCAS STOCEM ammunition tonnage expended may be due, in part, to the inability of the STOCEM to model exceptional logistical circumstances causing road/rail congestion and transport shortages during the historical campaign.

(b) Excessive STOCEM Movement and Losses While Attacking. For movement, nonartillery weapon losses, and personnel casualties, the ARCAS STOCEM divergence from history tends to be larger in the first few days of the campaign and when the US/UK is counterattacking in the last half of the campaign. These results indicate a tendency for ARCAS forces modeled in STOCEM to move faster than history and to lose both personnel and weapon systems, excepting artillery, at a somewhat faster rate than history, especially when a large part of one force is attacking.

(c) Conservation of US/UK Weapon Systems. The negligible historic US/UK APC and AT/M losses after D+8 suggest a successful US/UK policy of conserving mechanized systems by reducing their vulnerability and exposure after D+8. Such a policy was apparently not reflected in STOCEM decision threshold inputs.

(2) Input-dependent

(a) Underestimation of Ammunition Weights and Factors. Contributing to the excessively large German ARCAS STOCEM ammunition expenditure may be underestimation of single round ammunition weight inputs and ammunition expenditure factor inputs to STOCEM.

(b) Excessively High Move Rate Inputs. The ARCAS STOCEM move rate inputs are too high because they reflect a potential movement capability not generally achievable in real combat. Actual combat movement is also degraded by tactical, weather, and logistical considerations that cannot be explicitly modeled by STOCEM.

(c) Inappropriate Vulnerability Inputs. In Combat Sample Generator (COSAGE) inputs to ARCAS, vulnerability and/or exposure of AT/Ms may have been overestimated, while vulnerability of artillery may have been underestimated.

c. What implications on the validity of the STOCEM theater combat simulation process can be derived from the comparison of ARCAS STOCEM results with those from history?

(1) FEBA Progress. ARCAS base case STOCEM maximum FEBA penetration was very similar to history and was greater than the maximum FEBA advance for the STOCEM excursion case. These results support the credibility of the STOCEM representation of combat and movement.

(2) Ammunition Expenditure

(a) The similarities, in both trend and magnitude, of ARCAS STOCEM and historical US/UK ammunition expenditures support the credibility of the STOCEM representation of US/UK ammunition tonnage expenditure. Historical and STOCEM German cumulative ammunition expenditures are very similar, in both magnitude and trend, after a constant multiplicative scaling adjustment is applied to STOCEM ammunition round weight inputs.

(b) The higher US/UK ammunition expenditure in the ARCAS excursion case is plausible, since reinforcing units in the excursion case are allocated to the "neediest" sectors in theater, where they would likely confront more opposition (and targets) than in the base case which restricted reinforcing units to their historically supported sectors. The differences are credible.

(3) Weapon System Losses. ARCAS STOCEM tank losses and APC losses are similar to historical values during the first half of the campaign. If the catastrophic breakthrough effects of the initial German attack, not amenable to modeling, are discounted, then both history and STOCEM show negligible US/UK artillery losses. These similarities all give support to STOCEM credibility.

(4) Personnel Losses. The similarities between ARCAS STOCEM and history in magnitude and trend of cumulative STOCEM total casualties over time give support to ARCAS STOCEM credibility. The trend similarities between STOCEM and history in US/UK DNBI fraction and CMIA fraction also enhance the credibility of the STOCEM combat representation.

d. What changes in STOCEM, the kind of inputs it uses, or the way the model is applied are suggested by this comparison as appropriate for future simulations? The key areas of investigation for STOCEM input and logic modification derived from the ARCAS STOCEM/history comparisons are summarized in Table 1-2. They include:

(1) FEBA Progress

(a) Logic-driven

1. Investigate methods which moderate the STOCEM-calculated move rate capability (in selected force postures) in response to a "sufficiently sustained" rapid combat advance. That is, simulation realism, based on ARCAS historical results, appears to require a "pause" to be programmed into STOCEM movement following multiple successive time periods (cycles) of continual attack activity by the same unit.

2. Modify STOCEM logic to force each STOCEM unit to stop at input-specified objective positions. (Current STOCEM permits movement up to 10 kilometers (km) beyond objectives.)

(b) Input-driven. Investigate reducing ARCAS input move rates for the attacker.

(2) Ammunition Expenditure

(a) Input-driven. Reevaluate input ARCAS German ammunition round weights and investigate revising them as required. Care should be taken to make ARCAS STOCEM ammunition weight inputs consistent with the basis for calculation of ACSDB ammunition tonnage.

(3) Weapon Losses

(a) Logic-driven

1. Investigate methods which reduce an attacking force's basic STOCEM lethality against enemy tanks and APCs, with a higher reduction associated with a higher strength advantage (for the attacker).

2. Investigate methods which enable STOCEM to simulate a "conservative use" policy for a force's mechanized weapon systems. Such a policy sharply reduces the vulnerability of mechanized systems after a period of heavy losses when favorable attack conditions have been created.

3. Investigate methods which enable STOCEM to simulate, for a limited duration, a "breakthrough" combat attack posture which generates significantly accelerated defender attrition and is related to attacker speed and an overwhelming attacker force advantage.

(b) Input-driven. Investigate reducing ARCAS input vulnerability of armor and AT/M systems. Investigate increasing the input vulnerability of artillery systems.

(4) Personnel Casualties

(a) Logic-driven

1. Investigate methods which reduce an attacking force's basic STOCEM lethality against enemy personnel, with a higher reduction associated with a higher strength advantage (for the attacker).

2. Investigate adoption of a revised rule for redistributing personnel casualties over the four casualty types (KIA/WIA/CMIA/DNBI). A new redistribution rule was developed by using the observed differences between history and STOCEM. This rule, or variants of it, should be examined for use in the STOCEM processor logic which partitions personnel casualties.

3. Investigate methods which enable STOCEM to simulate a "breakthrough" combat attack posture which generates significantly accelerated defender CMIA and DNBI casualties and is related to attacker speed and an overwhelming attacker force advantage.

(b) Input-driven. Consideration should be given to reducing ARCAS input personnel vulnerabilities of personnel engaging an attacking force.

Table 1-2. Areas of Investigation for STOCEM Input/Logic Modification

Outcome type	ARCAS STOCEM input modification	STOCEM logic modification
FEBA	Reduce input move rates of attacker	(1) Reduce move rate after a sustained advance (2) Stop unit movement at a set objective
Ammunition expenditure	Revise German single round weight inputs	
Weapon system losses	(1) Reduce vulnerability of armor & AT/M systems (2) Increase vulnerability of artillery (3) Simulate conservation of mechanized systems when strength is sufficient	(1) Reduce lethality of an attacking force (2) Simulate conservation of mechanized systems when strength is sufficient (3) Simulate accelerated attrition during a catastrophic breakthrough
Personnel losses	(1) Reduce vulnerability against an attacking force (2) Change partition of casualties into KIA/WIA/CMIA/DNBI	(1) Reduce lethality of an attacking force (2) Change partition of casualties into KIA/WIA/CMIA/DNBI (3) Simulate accelerated CMIA and DNBI during a catastrophic breakthrough

CHAPTER 2

STUDY APPROACH AND METHODOLOGY

2-1. INTRODUCTION

a. Role of Systems Analysis in Military Planning. Two "old soldier's" views of the worth of systems analysis in war are :

- *"Unhappy the general who comes on the field of battle with a system"* - ***Napoleon I, Military Maxims (1827)***
- *"Courage comes from the exact computation of the probabilities."* - ***Rene Quinton, Soldier's Testament (1930)***

Napoleon clearly felt that excessive reliance on systems analysis was a poor (even disastrous) way to wage a battle. Quinton, a century later, believed that it was needed in the planning for battle. A modern proponent of systems analysis models would likely substitute "confidence" for "courage" in Quinton's statement and would also qualify "exact computation" into a form allowing "best approximations." The role of systems analysis is not to replace the military decision maker, but to advise him by providing information concerning the possible consequences of alternative courses of action. The military analyst deals in probabilities, possibilities, and trends. The results of systems analysis provide added perspectives which, combined with planners' experience, enable better military decisions. The combat simulation model is one tool used by the systems analyst.

b. Combat Simulation Model Use at CAA. The US Army Concepts Analysis Agency (CAA) is designated as the Army's Center for Strategy and Force Evaluation. CAA is assigned the primary mission of assessing strategies, strategic concepts, broad military options, resource allocation alternatives, and analyzing Army force-level capabilities in the context of joint and combined forces. Computerized combat simulations are used by CAA to assess capabilities of forces engaged in conflict scenarios of interest to Army decision makers and to develop requirements for Army replacement equipment, personnel, ammunition, and support force structure. Combat models used at CAA are continually being assessed for potential improvements or corrective actions, based on experience and/or expert judgment by analysts and/or decision makers.

c. Model Credibility Requirements. Questions have arisen as to how reliably large-scale (theater-level) combat simulations reproduce the "real world." These questions have taken on new importance with the proliferating use of combat simulations in the planning and preparation for war. The worth of a simulation model is reflected in the credibility of the results which it generates. The Department of the Army, in AR 5-11 (Ref. 1), establishes a verification and validation process for assessing the credibility of a combat model. Verification establishes that the model's software is free of programming bugs and performs as intended. Validation establishes that the model's performance is indeed the correct performance, i.e., that the model's results are true.

d. Validation of a Combat Simulation. Within the Department of the Army, validation of a simulation model is defined as the process of determining that the model is an accurate representation of the intended real-world entity from the perspective of the intended use of the model. In the strictest sense, a combat model must be validated by selecting an actual conflict of forces in the "real world" as a baseline and then representing and reproducing the attributes, components, and events of that baseline conflict in the combat simulation. Because the "real world" is subject to stochastic variation, combat processes and events can only be approximated in a simulation. The broad scope of the many entities (e.g., units, weapons), processes, and events in theater-level combat simulations makes validation difficult. Defining and describing a theater campaign/conflict for treatment in a combat simulation also requires a large data collection/processing effort which must be keyed to simulation input requirements.

2-2. BACKGROUND

a. Origin and Initial Objective. In 1987, the Director, CAA, proposed that a WWII campaign be selected for representation in a theater combat simulation at CAA. World War II theater operations offer scenarios employing large land forces and armored units. Campaigns in WWII offer opportunities for assessing credibility and validity of combat simulations. Large tank battles are of special interest for Army analysis because both current and projected future land warfare scenarios employ significant tank firepower. A screening of WWII campaigns resulted in selection of the 1944-45 Ardennes Campaign (also known as the Battle of the Bulge). The ARCAS Study uses historical data from this campaign as input to a combat simulation model. Using historical data to set initial scenario conditions and force objectives, the campaign is simulated. Simulation results are compared with history data and are also used to assess credibility and validity of the combat simulations as well as needed changes and/or improvements in rules, algorithms, and capabilities of the combat model employed.

b. Historical Data Base Development. In September 1987, the Historical Evaluation and Research Organization (HERO) was issued a contract to construct a comprehensive history data base describing the WWII Ardennes 1944-45 Campaign data base in sufficient detail for simulation. Historical data from forces in the Ardennes Campaign were collected, under contract, and were reformatted into a computerized data base formatted in DBASE IV. The contractor used primary and secondary sources on file at libraries and archives in the United States, Great Britain, and the Federal Republic of Germany. This data base, designated as the Ardennes Campaign Simulation Data Base, was completed in December 1989 by Data Memory Systems, Incorporated (Refs. 2, 3).

c. Simulation Model Selection and Application. The ACSDB was used to define initial conditions and force objectives which enabled simulation of the Ardennes Campaign by a CAA theater-level combat simulation, the STOCEM, a stochastic version of the CEM IX. The ARCAS Study used the ACSDB to develop scenario inputs for STOCEM, including:

(1) The initial force deployment/layout conditions of the campaign.

(2) The general intent/initial scheme of maneuver of forces.

(3) The timing of additional force availabilities for commitment.

The intent of ARCAS was not to adjust model inputs to force results to mimic history, but to exercise STOCEM from the simulated perspective of a WWII commander who possessed only the above three planning factors and intelligence represented in the ACSDB.

d. Purpose of ARCAS. The purpose of the ARCAS Study is to determine how, where, and why patterns of simulated STOCEM combat are similar to, or differ from, patterns reflected in the historical records represented by the ACSDB. Similarities between trends in STOCEM outcomes and history can provide support for model validation (of STOCEM/CEM). If a STOCEM trend differs substantively from the historic outcome, then, if a rationale for that historical trend can be discerned, justified, and quantified, it can become the basis for a modification of the STOCEM combat model logic which will improve STOCEM realism and credibility. The ARCAS Study offers a unique opportunity to base evolving combat simulation model design on both theory and historical results.

2-3. APPROACH. The ARCAS methodological approach is graphically summarized in Figure 2-1.

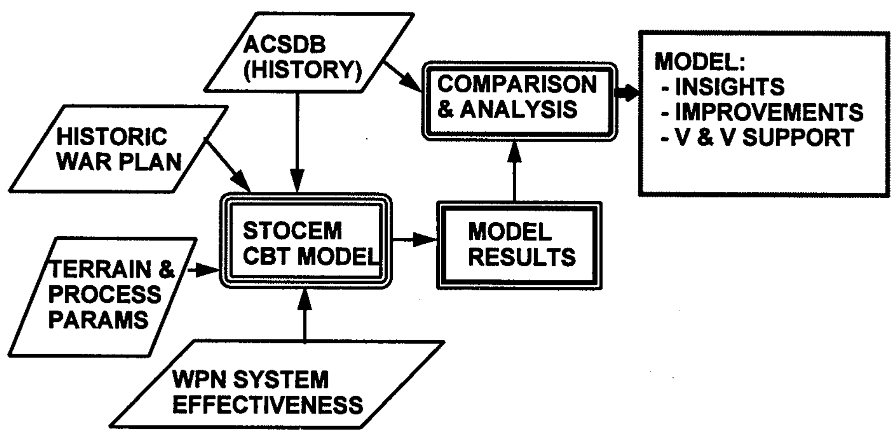


Figure 2-1. ARCAS Methodology Approach

The combat simulation selected for the effort was the STOCEM developed by, and used at, CAA. The STOCEM is a stochastic version of the CEM IX, which is an operational combat simulation used at CAA to assess capabilities and requirements of forces in theater-level scenarios. The study approach phases included the following:

a. The input data for the Ardennes Campaign was formulated for the STOCEM using:

(1) Initial Conditions from a History Data Base. The historical data base used by ARCAS is a computerized data base designated as the ACSDB. The initial positions, configuration, strengths, compositions, and availabilities of forces for the campaign, as depicted in the ACSDB, were used to define the force laydown for STOCEM.

(2) Historical War Plans. Documentation on the intended war plan of the German forces was used to define the objectives and avenues of attack for the STOCEM force laydown. The ACSDB was used to define where the divisions and brigades were positioned at the start of combat. War plans were used to define where corps and armies were directed after combat began.

(3) Weapon System Effectiveness Data. Effectiveness parameters (e.g., range, rate of fire, lethal area/probability of kill given a hit) of weapon systems employed in the Ardennes Campaign were generated for input into a STOCEM preprocessor, based on their WWII employment conditions. Intrinsic munition effectiveness measures not available in WWII historic data were determined by interpolation and/or extrapolation of test results from comparable weapons.

(4) Terrain and Processing Parameters. Maps showing topography of the campaign area were used to define and locate terrain types impacting on mobility potential. These terrain types and locations are overlaid on the STOCEM avenues of advance. A number of parameters regulating model combat algorithms are also input.

b. STOCEM is executed to produce simulated combat outcomes which are then compared with the actual historical outcomes, as represented in the ACSDB. Every effort is made to ensure that the STOCEM measures and the associated ACSDB values reflect the same scenario conditions; i.e., they are based on the same set of units, weapon types, geography, and employment doctrine.

c. Similarities and differences between the simulated and the historical combat trends and patterns are then described and used to:

(1) Assess STOCEM's fidelity to the historical campaign's general development.

(2) Highlight areas where improvements may be made in STOCEM logic/algorithms to better reflect actual combat, as reflected in the ACSDB. When combat simulation results and trends differ substantively from history, reasons are sought to explain the differences. If a causal factor for a historical trend is not represented in the model, then consideration is given to recommending that the combat model logic be modified to treat the omitted factor. However, differences (between model and history) can be the basis for change only if they are supported by plausible underlying military rationale.

(3) Provide evidential data on STOCEM validation by assessing the degree to which STOCEM is an accurate representation of the real world from the perspective of its intended use.

If trends in the combat simulation results are similar to historical results, then the appropriateness of the combat model's underlying logic gains credibility.

2-4. ARDENNES CAMPAIGN SIMULATION DATA BASE (ACSDB). The ACSDB tracks data for divisions and for independent/separate brigade-size units on a daily basis. The structure of the ACSDB is summarized in Table 2-1.

Table 2-1. ACSDB Structure

Data file		Type data
Unit Data Base		Personnel, ammo, fuel, and supply status by unit
Unit Inventory Data Base		Weapon/vehicle status by unit
Unit Location Data Base		Unit locations and activities
Air Data Base		Daily air sorties and activity
TOE Data Base		Authorized strengths by unit type
Weapons Data Base		Weapon and vehicle characteristics
Reference Data Base		Sources of ACSDB data
Bibliography Data Base		Supplemental document titles about Ardennes Campaign

The ACSDB includes the following eight files:

a. Unit Data Base. The Unit Data Base contains personnel, medical, and logistical statistics on ground combat units of US, British, and German forces that were in, or supported, the Ardennes Campaign theater of operations in the Ardennes battle. Unit information, provided for each unit on each day of the campaign, includes:

(1) Number of personnel casualties. Casualty type categories include KIA, WIA, CMIA and DNBI. The number of WIA and DNBI entering hospital is also noted, as are deaths in hospital.

(2) Number of onhand, replacement, and returning personnel.

(3) Amounts of ammunition, fuel, and other supplies onhand, received, and consumed during the course of the campaign.

b. Unit Inventory Data Base. The Unit Inventory Data Base contains data on equipment (weapons and vehicles) strengths and losses of US, British, and German combat units. Information on unit weapon/vehicle status recorded for each day during the course of the campaign includes the onhand amount, the number damaged, the number destroyed in combat, the number abandoned, number of replacements, number in repair, and the number returning from repair.

c. Unit Location Data Base. The Unit Location Data Base records information on the location, during the campaign, of US, British, and German combat units, including divisions, corps, armies, and separate brigades. It also provides some information on the activities, operations, and missions of ground combat units.

d. Air Data Base. The Air Data Base contains information on US, British, and German tactical air sorties flown during the campaign. Information, recorded for each day, includes the number of sorties for each type of sortie and aircraft. Locations of air bases used in the campaign are also recorded.

e. Table of Organization and Equipment (TOE) Data Base. The TOE Data Base shows data from official TOE lists for all US, British, and German battalion-, regiment-, brigade-, and division-size units in the ACSDB. Authorized personnel, equipment, and logistics strengths are provided for each unit.

f. Weapons Data Base. The Weapons Data Base records information on equipment (weapons and vehicles) characteristics. Weapon system characteristics include movement rates of vehicles and aircraft, ammo weight carried, basic ammunition load, maximum effective range, rate of fire, sensor type, and range.

g. Reference Data Base. The Reference Data Base records the sources of the data and information in the other data base files.

h. Bibliography Data Base. The Bibliography Data Base lists additional documents describing aspects of the personnel, systems and/or events of Ardennes Campaign.

2-5. THE STOCHASTIC CONCEPTS EVALUATION MODEL (STOCEM). The STOCEM is a stochastic version of the combat simulation denoted as the Concepts Evaluation Model IX. STOCEM characteristics are documented in a CAA report (Ref. 4) and are summarized in Figure 2-2. Characteristics of the CEM IX which are also applicable to STOCEM are described below, followed by a description of the stochastic processes unique to STOCEM. CEM IX is documented in CAA reports (Refs. 5, 6). CEM IX is a two-sided (denoted as Blue and Red forces), fully automated, deterministic theater combat simulation which is used to assess force capability and to develop requirements in supporting the US Army force structuring process. Theater wars of up to 270 days' duration have been simulated.

- **FULLY AUTOMATED SIMULATION**
  - ✓ **Two sided combat in 12-hour cycles**
  - ✓ **Decisions on allocation, commitment, missions of forces**
  - ✓ **Movement along/across specified avenues of advance**
  - ✓ **Killer/victim weapon data used to extrapolate losses**
- **STOCHASTIC VARIATION**
  - ✓ **Decision Thresholds for allocation & commitment**
  - ✓ **Weapon effectiveness parameters**
  - ✓ **Probability of destruction(kill) given a hit**
  - ✓ **FEBA move rate produced by a tactical situation**

Figure 2-2. STOCEM Characteristics

a. CEM IX Characteristics

(1) Units are resolved in terms of Blue brigades and Red divisions. Unit combat is simulated in 12-hour (simulated time) cycles.

(2) Decision logic is executed at fixed time intervals associated with simulated command levels corresponding to unit (division), corps, army, and theater. Simulated decisions at levels below theater include mission selection, reserve commitment and reconstitution, and apportionment of direct support (DS) and general support (GS) from artillery and close air support (CAS). Corps- and army-level (simulated) decisions also include assignment of reinforcing divisions and realignment of subunit (divisions in corps and corps in armies) frontage in response to a changing tactical situation. Primary theater cycle decisions include assignment of reinforcement artillery to armies, allocation of CAS sorties to armies, and the allocation of supplies and replacements.

(3) The CEM battlefield terrain grid is overlaid with a system of corridors corresponding to the initially planned flow of forces in the campaign. These corridors are denoted herein as CEM "avenues of advance." These avenues of advance are further partitioned into narrow strips called minisectors for higher resolution representation of unit frontage. This frontage may be adjusted dynamically by the simulated decision processes in response to changes in tactical situations, e.g., a defending or delaying corps may adjust the frontage of its component divisions in an effort to "even out" the threat against it and to reduce any salients into its region or penetrations along its flank. Unit combat engagements are characterized by the composition of engaged units, the unit missions, and the associated terrain.

(4) During the 12-hour unit combat cycle, after the rounds available to shooters have been determined, an attrition processor called ATCAL (Attrition Model Using Calibrated

Parameters) is used to determine combat losses during the period. Intrinsic weapon effectiveness data (e.g., range, rate of fire, lethal area/probability of kill given a hit) of individual weapon system types, their conditions of use, and their potential target types are input. Another program, the COSAGE, preprocesses weapon effectiveness data for STOCEM and supports ATCAL by stochastically simulating fire and attrition over a spectrum of small engagements and generates a large number of "engagement tables" which reflect kills per round fired for a large spectrum of shooter type-target type and engagement/posture combinations. During STOCEM execution in a simulated combat cycle, the ATCAL processor extrapolates and interpolates the appropriate COSAGE-generated "engagement tables" (for the forces and engagement type involved) to yield the resulting attrition of systems and personnel.

b. Stochastic Aspects of STOCEM. STOCEM introduces stochastic (probabilistic) variations into combat processes and decisions to yield, through repeated application, a distribution of possible battle outcomes. Such a distribution can provide decisionmakers and analysts with information on the risks associated with specific scenarios. Stochastic processes modeled in STOCEM include:

(1) Decision processes regulating mission selection and commitment of forces.

(2) The weapon attrition obtained from ATCAL results. In STOCEM, ATCAL results reflect the stochastic variation in weapon system effectiveness over a spectrum of tactical engagement scenarios and postures.

(3) Quantities of damaged weapon systems that are killed or abandoned and the quantities of combat personnel casualties that are killed, wounded, hospitalized, and evacuated.

(4) The attacker's rate of advance produced by tactical situation parameters such as terrain, posture, and the relative combat losses of the combatant units.

2-6. ARCAS STOCEM SCENARIOS MODELED

a. STOCEM Representation of the Campaign Area . Figure 2-3 is an annotated map showing the geographic area for the Ardennes Campaign used in the basic ARCAS scenario. The map area is overlaid with a system of 21 movement corridors, denoted herein as CEM "avenues of advance," corresponding to the initially planned flow of forces in STOCEM during the campaign. These avenues are serially indexed from north-to-south as avenue #10 through #30 (as indicated on the right side of the figure) and are used in a number of figures exhibited within this report. These indexed avenues provide a convenient way of representing FEBA progress on a Cartesian coordinate system (as km progress in each avenue of advance) which has a geographic order and is also consistent with the theater structure used in STOCEM. Locations of major cities are also annotated on this chart and in subsequent charts of FEBA progress. The northern boundary of the scenario area corresponds approximately to the positions of the US 2d Infantry Division (ID) and the opposing 277th Volksgrenadier Division (VGD). Engagements north of these positions were basically holding actions with limited contribution to the historical "bulge." The easternmost points on the avenues in Figure 2-3 are at the approximate initial positions of the online German forces on December 16, 1944 (denoted herein as D-day).

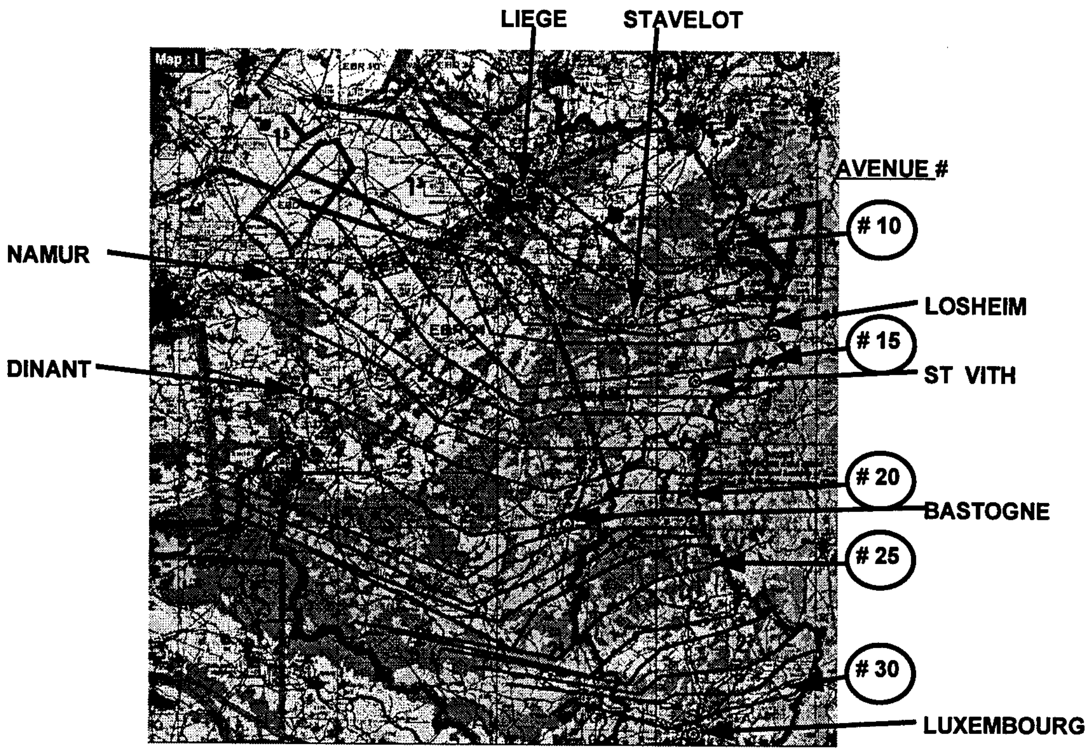


Figure 2-3. STOCEM ARCAS Theater Representation

b. ARCAS STOCEM base case Scenario Conditions. The STOCEM simulation scenario which represents the historical Ardennes Campaign is designated herein as the ARCAS STOCEM base case. Appendix D has a comprehensive listing of the compositions and strengths of forces simulated in this scenario. This paragraph defines overall scenario conditions and the time-phasing of units deployed in the ARCAS STOCEM base case scenario. The ARCAS STOCEM base case scenario is characterized by the following:

(1) Timeframe. The scenario timeframe was December 16, 1944 (D-day) to January 16, 1945.

(2) German Line Unit Deployments. The German Armies in the D-day scenario are, from north-to-south, the 6th Panzer Army, the 5th Panzer Army, and the 7th Panzer Army. Twelve units (mostly divisions) are online and engaged at D-day. A further 16 line units reinforce these during the campaign. The time-phasing of units committed to combat is shown in Table 2-2. The scenario availabilities for commitment were based upon the days when initial combat engagement was first reported for each unit in historical data. STOCEM reinforcement input for both sides was resolved so as to phase units in at 2-day cyclic intervals. Detail on personnel and equipment strengths is shown in Appendix D.

(3) US/UK Line Unit Deployments. The US/UK forces in the D-day scenario are, as positioned from north to south, elements of US V Corps, US VIII Corps, and US III Corps. Six US divisions are online and engaged at D-day. A further 24 line units (21 US and 3 UK) reinforce these during the campaign. Detail on the time-phasing of line unit reinforcements is shown in Table 2-2. Names of the three British line units gamed in the scenario are prefixed with (UK) in the table.

Table 2-2. Time-phasing of Line Unit Availability for Commitment

Day	US/UK unit	German unit
D-day	99th ID	277th VGD
	2d ID	18th VGD
	106th ID	62d VGD
	28th ID	560th VGD
	9th AD	12th VGD
	4th ID	116th PzD
		2d PzD
		26th VGD
		5th FJD
		276th VGD
		352d VGD
		212th VGD
D+1	30th ID	3d FJD
	7th AD	1st SSPzD
	10th AD	12th SSPzD
		PzLehrD
D+3	1st ID	9th SSPzD
	101st AbnD	2d SSPzD
D+5	84th ID	150th PzBde
	82d AbnD	3d PzGD
	3d AD	FBB
	80th ID	340th VGD
	5th ID	
	4th AD	
D+7	26th ID	FGB
		79th VGD
D+9	75th ID	9th PzD
	2d AD	15th PzGD
	(UK) 29th Arm Bde	
D+11	35th ID	
D+13	83d ID	
D+15	11th AD	167th VGD
	87th ID	9th VGD
	6th AD	
D+19	(UK) 53d ID	
	17th AbnD	
D+25	(UK) 51st ID	
	90th ID	

(4) Echelons Above Division. The ACSDB includes both line units and headquarters units. STOCEM direct fire engagements are only between line units, but higher echelons allocate fire support over their area of control. Attrition in STOCEM is simulated only for line units and supporting artillery units. STOCEM also represented fire support from the following headquarters units above division level:

(a) German: 5th Panzer Army (PzArmy), 6th PzArmy, 7th PzArmy, I SS Panzer Korps (SSPzK), II SSPzK, XIII Panzer Korps (PzK), XXXIX PzK, XLVII PzK, LVIII PzK, XIII Korps (K), LIII K, LXVI K, LXVII K, LXXX K, LXXXV K, Korps Felber, and Korps Decker.

(b) US/UK: US 1st Army, US 3d Army, US III Corps, US V Corps, US VII Corps, US VIII Corps, US XII Corps, US XVIII Corps, and British XXX Corps

(5) Reinforcement Policy. The STOCEM base case partitioned each theater force into three areas of operations, corresponding approximately to major Army areas. STOCEM then directed each reinforcing unit (for both sides) to the area of operations which it historically supported.

c. ARCAS STOCEM excursion case Scenario Conditions. A STOCEM excursion case scenario was defined as having all conditions identical to the above-described STOCEM base case except for a different reinforcement policy characterized as follows:

ARCAS STOCEM excursion case Reinforcement Policy. In the STOCEM excursion case, each theater force is associated with a single sector of operations corresponding to the entire campaign theater. STOCEM then directs each reinforcing unit (for both sides) to an algorithmically-chosen location which may be anywhere in the theater. The choice of location is based on the relative force ratios of the opposing units.

d. Battlefield Implications of ARCAS STOCEM Scenario Conditions. The STOCEM base case is the closer analogue to history since it is explicitly keyed to the historical reinforcement policy. In the STOCEM excursion case, the STOCEM logic, using "perfect intelligence" on unit status, attempts to reinforce the units having the largest attacker/defender ratio at the arrival time of the reinforcements. The intent of this reinforcement logic is to reinforce success in the offense and weakness in the defense. The historical battle's reinforcement scheme, represented in the STOCEM base case scenario, did not employ perfect intelligence of battle status; therefore, it would likely be associated with a less efficient US/UK countering of the German attack in the "bulge" than is represented in the STOCEM excursion case.

2-7. MEASURES OF EFFECTIVENESS. For each scenario case, measures of effectiveness (MOEs) describing FEBA progress, personnel casualties, and system kills were computed from both the STOCEM outcome and the historical data base. Since STOCEM is a stochastic simulation, measures (described below) showing dispersion of results were computed in addition to the simple arithmetic average value over the 16 replications. Outcome values from the ACSDB historical data were treated as constants (although, as will be noted later, significant uncertainty exists in MOEs based on the reported values).

a. Comparative Measures Used. The types of MOEs selected are summarized in Figure 2-4.

- **FEBA PROGRESS (KM ADVANCED FROM D-DAY)**
  - ✓ Shown on each linearized CEM avenue of advance
  - ✓ Map overlay generated by Terrain Evaluation Module
  - ✓ Assessed at 4-day intervals
- **SYSTEM KILLS**
  - ✓ Killed or abandoned weapon systems (by generic type)
  - ✓ Assessed at 4-day intervals
- **PERSONNEL CASUALTIES/CASUALTY RATES**
  - ✓ Assessed each day for US/UK Force
  - ✓ Personnel KIA,WIA,CMIA and DNBI
  - ✓ Daily rates expressed as casualties per thousand onhand

Figure 2-4. Measures of Effectiveness Computed and Compared in ARCAS

(1) FEBA Progress. The FEBA progress at 4-day intervals is expressed as the total km advance accomplished by the German force since D-day. This FEBA progress is then graphically represented in two different ways:

(a) Linear Cartesian Plots. FEBA progress is first measured as a linear distance along each of the 21 STOCEM avenues of advance (those shown and indexed in Figure 2-3). These measurements then become the basis for a Cartesian quasi-geography of the FEBA status with the y-axis showing the FEBA progress represented as parallel straight lines along the avenues of advance (which are ordered north-south along the x-axis).

(b) Map Overlays. The Terrain Evaluation Module, a US Army software tool, was also used to overlay a digitized map of the campaign area with a FEBA line for selected days in the campaign. (The avenues of advance are omitted from these map plots.)

These plots portray the same FEBA progress in different ways. The linearized plots allow a more detailed analysis of the components of FEBA movement.

(2) System Kills. Both cumulative and single-period status charts are shown. The cumulative charts portray cumulative system kills for a generic class of weapon system (e.g., tanks) as a function of elapsed time (D-day through D+32 in the ARCAS STOCEM scenario) at 4-day intervals in the scenario. D-day throughout this paper denotes the ARCAS STOCEM scenario D-day, which is 16 December 1944, the beginning of the historical Ardennes Campaign, as recorded the ACSDB. The single-period charts display total system kills in each 4-day interval during the campaign. A system is defined as "killed" if it is destroyed or is damaged and abandoned. Generic weapon system classes include tanks, armored personnel carriers, artillery, antitank systems, and mortars. The antitank systems and mortars are combined into a single class denoted as AT/Ms. For each side, STOCEM explicitly represents up to 12 different categories in each of the above 4 weapon classes. These categories, in each class, are combined into a single generic weapon class for the results presented in this paper.

(3) Personnel Casualties/Casualty Rates. Total casualties are assessed, at 4-day intervals, for both the German and US/UK forces. Total casualties are further partitioned over the four casualty types (KIA/WIA/CMIA/DNBI) only for the US/UK force. Charts for the US/UK force also show single-day casualties and average casualty rates at 2-day intervals throughout the campaign. Casualty rates for a given casualty type are expressed as casualties per thousand onhand personnel. Casualties are assessed only for line units and artillery units, not for echelons above division (corps/army headquarters, services support, etc.).

b. Treatment of Stochastic Effects. Figure 2-5 summarizes the measures describing the uncertainty in ARCAS measures of effectiveness. Quantifiable probabilistic uncertainty is present in the stochastic outcomes generated by STOCEM. However, uncertainty is also inherent in the definition of a FEBA based on the ACSDB.

- **MEASURES OF DISPERSION (16 REPLICATIONS)**
  - ✓ Mean (average) value
  - ✓ Maximum value
  - ✓ Minimum value
- **CONFIDENCE LIMITS**
  - ✓ 99% confidence limit bands around mean (<u>with Normality asssumption</u>)
  - ✓ defined as mean +/- 3.16 standard errors
  - ✓ equivalent to 90% confidence limit band (any distribution)

Figure 2-5. Measures Describing Uncertainty in ARCAS

(1) Probability Distribution of STOCEM Results. Since the object of using a stochastic simulation, such as STOCEM, is to represent the probabilistic variation in battle outcomes, special measures derived from the theory of sampling statistics are needed to quantify that uncertainty in terms of probabilities. Each ARCAS STOCEM scenario case (Base and Excursion) was executed in STOCEM exactly 16 times, with each execution (denoted as a replication) being a unique campaign outcome derived from a unique combination of stochastically sampled STOCEM combat events. The following statistical measures shown in Figure 2-5, were then applied to each of the MOEs described in Figure 2-4 to quantitively portray the range and likelihood of STOCEM combat outcomes for a case at a specified scenario time:

(a) Mean: the arithmetic average (also denoted as the mean) of a measure, at a specified scenario time, over all 16 replications.

(b) Maximum value: the largest value of a measure, at a specified scenario time, over all 16 replications. For the FEBA progress measure, the maximum corresponds to the westernmost position of the FEBA (since D-Day) over all 16 replications. This maximum is useful as an indicator of variability in the specific example (of 16 replications) used. Generalization beyond that use is not warranted.

(c) Minimum value: the smallest value of a measure, at a specified scenario time, over all 16 replications. For the FEBA progress measure, the minimum corresponds to the easternmost position of the FEBA (since D-day), at a specified time, over all 16 replications. This minimum is useful as an indicator of variability in the specific example (of 16 replications) used. Generalization beyond that use is not warranted.

(d) Confidence limits: the computed mean value, at a specified scenario time, is only a sample estimate because a different sample of 16 STOCEM replications would generate a different mean value. However, there is a theoretical "true mean" which corresponds to the average computed from an infinitely large sample. Although it is impossible to calculate this "true mean," the theory of sampling statistics (Ref. 7) allows the analyst, from the sample of 16 replications, to compute upper and lower limits which have a specified probability of containing (i.e., bounding) the "true mean." For ARCAS, these limits are defined, at a specified scenario time, as:

1. Upper 99 percent/90 percent confidence limit = mean + 3.16 standard errors

2. Lower 99 percent/90 percent confidence limit = mean - 3.16 standard errors

where, as statistically defined for our sample of 16, a standard error = (standard deviation/$\sqrt{16}$/. If it is assumed that the probabilistic distribution of average outcomes (for a STOCEM measure) is the normal probability distribution, then these are 99+ percent confidence limits; i.e., if the distribution of average outcomes is statistically normal, then there is a 99+ percent probability that the "true mean" lies between the above-defined upper and lower confidence limits. For sample sizes in excess of 30, the probability distribution of an average outcome so closely approximates a normal distribution that it can be treated as normal at the level of precision treated in this paper. Since the sample size is only 16, the above limits are not provable 99 percent confidence intervals. However, application of Chebyshev's theorem provides assurance that the limits defined above are, at worst, 90 percent confidence limits regardless of the underlying probability distribution. (Random sampling is assumed.) If the sample size is increased, the associated 99 percent/90 percent confidence limit values will be closer to the mean. In charts representing a measure over elapsed time (D-day through D+32), the mean value, at a specified time, is represented by a column above the day label. The top of that column is then bounded in the vertical (y-) values by four lines corresponding to the maximum, minimum, the upper 99 percent/90 percent confidence limit, and the lower 99 percent/90 percent confidence limit for that mean, at a specified time. On charts in this paper, these upper and lower confidence limits are denoted (labeled) as +3.2 SE and -3.2 SE, respectively, because they are statistically associated with deviations from the mean of (approximately) 3.2 standard errors.

(e) Formulation Basis of Confidence Limits: For the sample size (16 replications) used in this paper, the use of the terms "lower 99 percent/90 percent confidence limit" and "upper 99 percent/90 percent confidence limit" are computationally equivalent to [arithmetic average - 3.16 standard errors] and [arithmetic average + 3.16 standard errors], respectively. If statistical normality of the parent population (from which the samples are drawn) is not assumed, then the above limits are equated, in this paper, to 90 percent confidence limits. However, if the normal distribution is assumed to apply, then these same limits are equated, in this paper, to 99+percent confidence limits. The specific formulations underlying these statements are given below:

1. Without Normality Assumption. Chebyshev's theorem, as applied in practice, by Schaum's Theory and Problems of Statistics and Econometrics (Ref. 7) :

" states that , regardless of the shape of the distribution, the proportion of observations (or area falling within K standard deviations of the population mean) is at least $1-(1/K^2)$ for K > 1. "

Setting $1-(1/K^2) = .90$ and solving for K, we get K = √10 = 3.16 and we conclude that, if we have a random sample of N observations (from an infinite population) in which the arithmetic mean of the sample is denoted as AVERAGE, then the population mean (i.e. the true mean) is approximately between AVERAGE - (3.16)(S) and AVERAGE + (3.16)(S) with a 90 percent level of confidence, where S denotes the standard error of the sample. Specifically S = (standard deviation of the sample observations)/√N. These limits apply even if the parent population is not assumed to be normally distributed.

2. With Normality Assumption. If we have a random sample of N observations from an infinite population which is ***assumed to be a normal distribution***, then we can use the t distribution to determine confidence intervals for the unknown population mean. If the arithmetic mean of the sample is denoted as AVERAGE, then the population mean (i.e., the true mean) is approximately between AVERAGE - (2.95)(S) and AVERAGE + (2.95)(S) with a 99 percent level of confidence, where S denotes the standard error of the sample, as defined above. The value of 2.95 is determined from the t distribution. These 99 percent confidence limits are two-tailed, i.e. in a very large random sample, essentially 1 percent of the sample will either be less than the lower confidence limit or will be greater than the upper confidence limit. Since the confidence limits represented by AVERAGE - (3.16)(S) and AVERAGE + (3.16)(S) are larger in spread than the 99 percent limits determined above, the associated level of confidence, with normality assumption, is higher than 99 percent. Therefore, they are denoted herein as 99+percent confidence limits with the normality assumption.

2-8. TREATMENT OF HISTORICAL FEBA. The analytic basis for a historical FEBA and the three types of historical FEBA used in ARCAS are summarized in Figure 2-6.

- **BASIS FOR HISTORY FEBA DEFINITION**
  - ✓ Unit locations recorded as multiple geographic points
  - ✓ Theater is partitioned into 21 CEM avenues of advance
- **BASE HISTORY FEBA**
  - ✓ Average position of westernmost 40% of German points on each STOCEM avenue of advance
- **HI HISTORY FEBA**
  - ✓ Westernmost German point on each STOCEM avenue of advance
- **LO HISTORY FEBA**
  - ✓ Average of all German points on each STOCEM avenue of advance

Figure 2-6. Basis for Historical FEBAs Applied in ARCAS

a. Analytic Basis for an Historical FEBA. The ACSDB does not define an historical FEBA. In the Unit Location File records of the ACSDB, each unit consists of multiple geographic points, each with a separate location. These multiple points include the latest reported location of the unit's headquarters, its left and right flank boundaries, and up to eight "reference points" giving the reported locations of its subelements. These component points form an irregular pattern and are often spatially commingled with points of other units. A first candidate definition for a FEBA consists of partitioning the theater into east-west strips, checking all German unit reference points on each strip, and then choosing the westernmost reference point to be the FEBA boundary on that strip. This approach was examined, using the 21 STOCEM avenues of advance, to partition the theater into east-west strips. However, it became apparent that the westernmost reference point of a German unit was highly unstable and was statistically less reliable than averaging unit reference points in a strip. This became analytically apparent when a US/UK FEBA, defined in terms of easternmost US/UK points, was analogously defined and compared with the (German) FEBA based on westernmost German unit reference points. Analysis indicated that, overall, these two types of FEBA were closest, on average, if the ARCAS base FEBA for a day was defined as the line connecting the average ACSDB location of the westernmost 40 percent of German ACSDB unit reference points in each STOCEM avenue of advance.

b. Base History FEBA. Based on the above rationale, a "Base History FEBA" was defined to represent the history FEBA on all charts herein which compare STOCEM FEBA progress with historical FEBA. The Base History FEBA is defined as the (line connecting the) average ACSDB location of the westernmost 40 percent of the German ACSDB unit location points on (i.e., closest to) each STOCEM avenue of advance. The Base History FEBA computed on a given day is based only on the German line units that have been actively entered into the campaign by that day in the STOCEM scenario. This restriction is needed to make the ACSDB FEBA consistent with the STOCEM scenario. This Base History FEBA is used as the "standard" History FEBA for comparison with STOCEM outcomes.

c. Measurement of Uncertainty in the Historical FEBA. Although only the Base History FEBA is used when comparing STOCEM with historical outcomes. The variability of FEBA definition inherent in the ACSDB data on unit location is also quantified, at 4-day intervals, using the following measures defining "bounds" in a region of uncertainty around the Base History FEBA:

(1) A "Hi History" FEBA is defined as the (line connecting the) single westernmost German ACSDB unit reference point on (i.e., closest to) each STOCEM avenue of advance. This Hi History FEBA is used as an estimator of the upper bound (maximum advance) of the History FEBA.

(2) A "Lo History" FEBA is defined as the (line connecting the) average ACSDB location of all of the German ACSDB unit reference points on (i.e., closest to) each STOCEM avenue of advance. This Lo History FEBA is used as an estimator of the lower bound (minimum advance) of the History FEBA.

As with the Base History FEBA, the above measures, on a given scenario day, are based only on the German line units that had been actively entered into the campaign by that day in the STOCEM scenario.

CHAPTER 3

ANALYSIS OF FEBA PROGRESS RESULTS

3-1. INTRODUCTION. The purpose of this chapter is to portray and compare the simulation and historical movement of the FEBA during the course of the Ardennes Campaign. Selected STOCEM results depict STOCEM and historical FEBA progress at 4-day intervals during the campaign. Measures of stochastic uncertainty in STOCEM results, based on statistical sampling theory, are also shown on most charts. Uncertainty in the definition of a historical FEBA is also partially quantified. A complete set of FEBA results developed from ARCAS is contained in Appendices E and F. Although some digitized map graphics are shown, most FEBA results are displayed in a stylized quasi-geographic Cartesian representation keyed to the attack avenues used in STOCEM. Observations impacting on simulation validation and recommendations for CEM logic modifications, to improve model realism, are developed from the STOCEM/history comparisons.

3-2. ARCAS STOCEM ENGAGEMENT POSTURE PROFILE. The STOCEM results for any time period in a scenario are related to the engagement postures of the committed units during that period. The engagement profile of the committed US/UK forces in the ARCAS STOCEM base case scenario is represented in Figures 3-1 through 3-3. Figure 3-1 shows the percent of the committed US/UK force in a static posture (neither side attacking in a sector) for each 4-day period in the STOCEM base case scenario. Figure 3-2 similarly shows the percent of the committed US/UK force in an attack posture, while Figure 3-3 shows the analogous percent of the committed US/UK force that is being attacked (by German forces) in each period. These comprise all engagement postures of the committed US/UK force during the scenario; therefore, the average posture percentages for any specific 4-day period will sum to 100 percent over Figures 3-1 through 3-3. The attack posture percentages shown in Figure 3-2 are further partitioned in Figures 3-4 and 3-5 according to whether the attacker was opposing a prepared defense or a hasty defense. Similarly, the defense posture percentages shown in Figure 3-3 are further partitioned in Figures 3-6 and 3-7 according to whether the defender was in a prepared defense or a hasty defense. Results for a delay defense posture are not shown because only a negligible percent of the US/UK force was in delay posture in ARCAS results. The analogous posture profiles for the STOCEM excursion case scenario are very similar and are not shown here. A comparable historical posture profile was not derivable from the ACSDB because of insufficient recorded mission/posture information. The vertical bars in Figures 3-1 through 3-7 show the mean (average) STOCEM posture percentage over all 16 replications during each 4-day period. The line graphs show the measures of stochastic uncertainty defined in paragraph 2-7. The dashed lines show the maximum and minimum values during each period over the 16 replications. The solid lines labeled + or - 3.2 SE are the 99 percent/90 percent confidence limit bounds for the STOCEM average posture percentage.

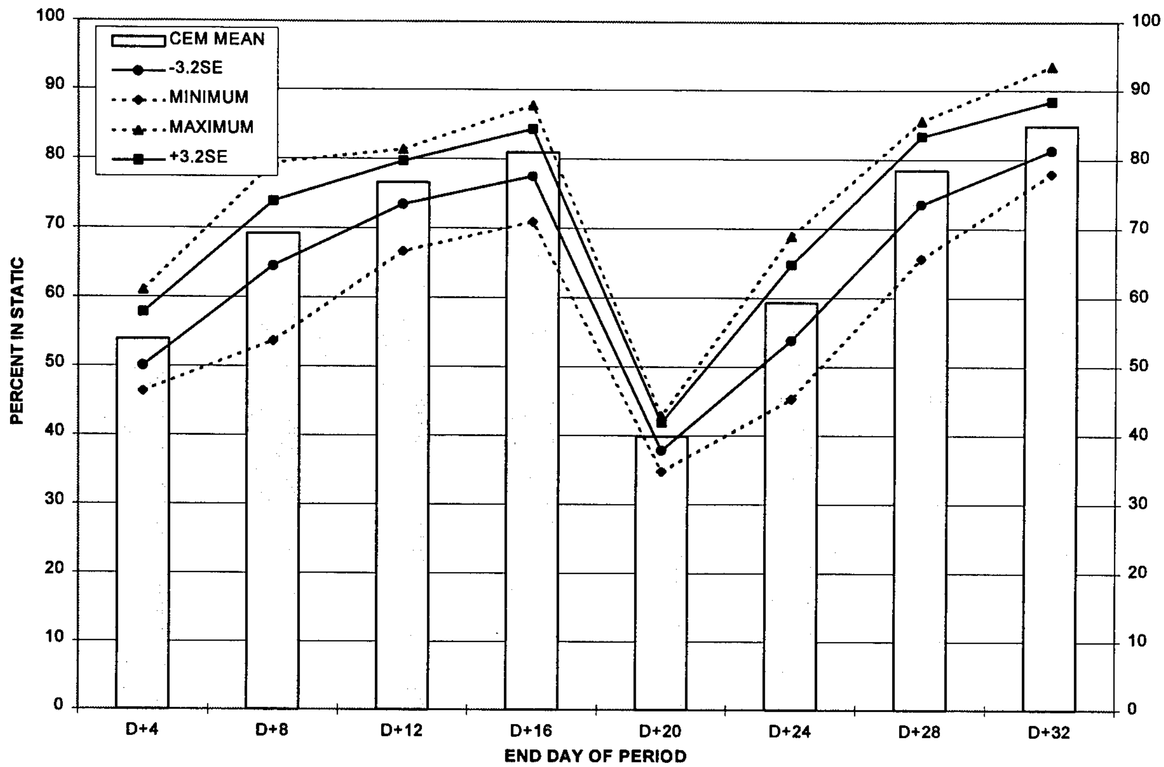


Figure 3-1. Percent of US/UK Committed STOCEM Force in Static Posture in Each 4-day Period (base case scenario)

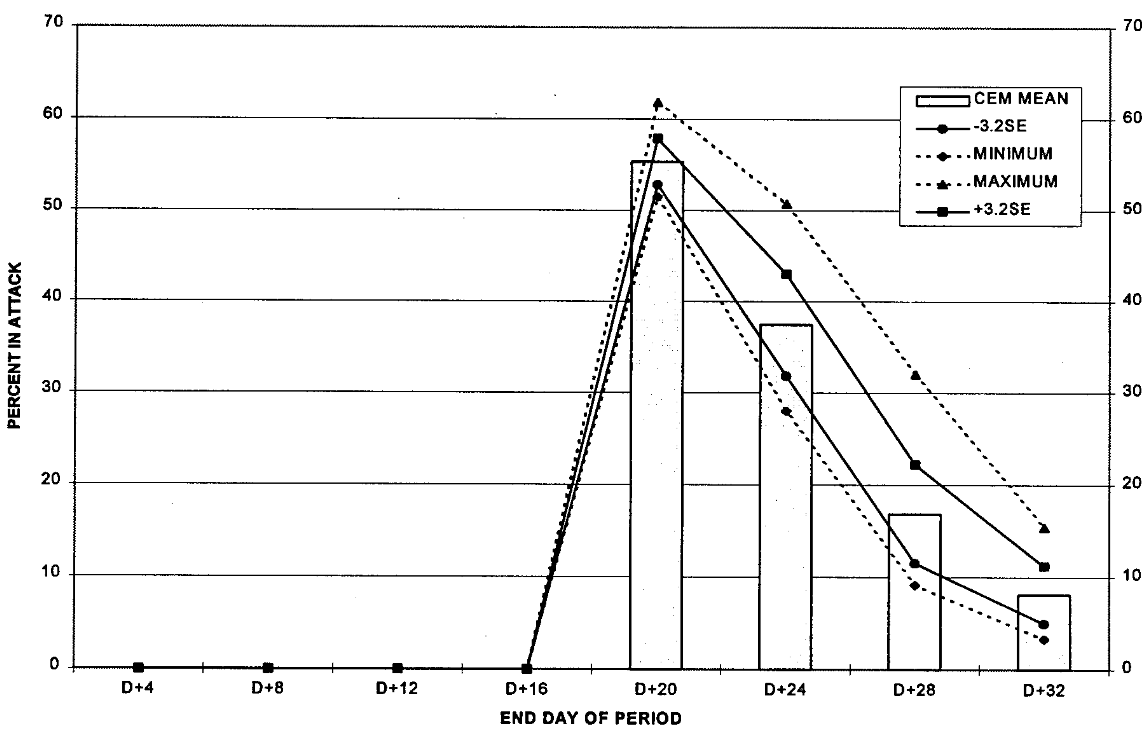


Figure 3-2. Percent of US/UK Committed STOCEM Force in Attack Posture in Each 4-day Period (base case scenario)

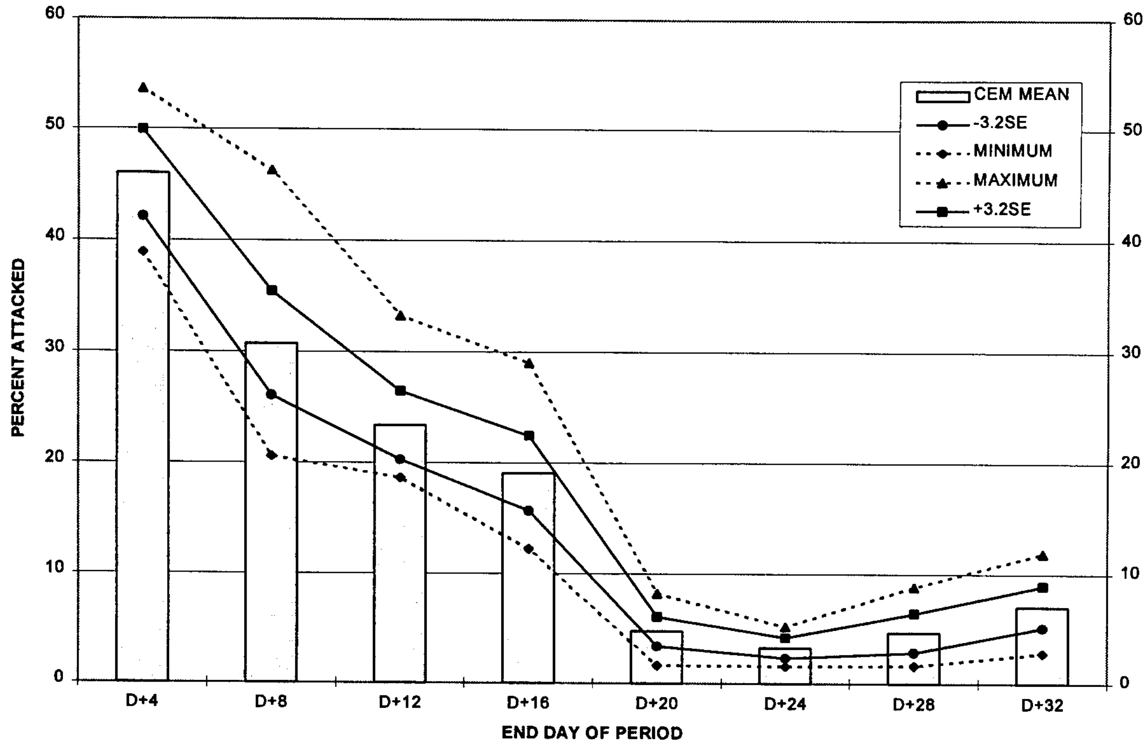


Figure 3-3. Percent of US/UK Committed STOCEM Force Attacked by German Forces in Each 4-day Period (base case Scenario)

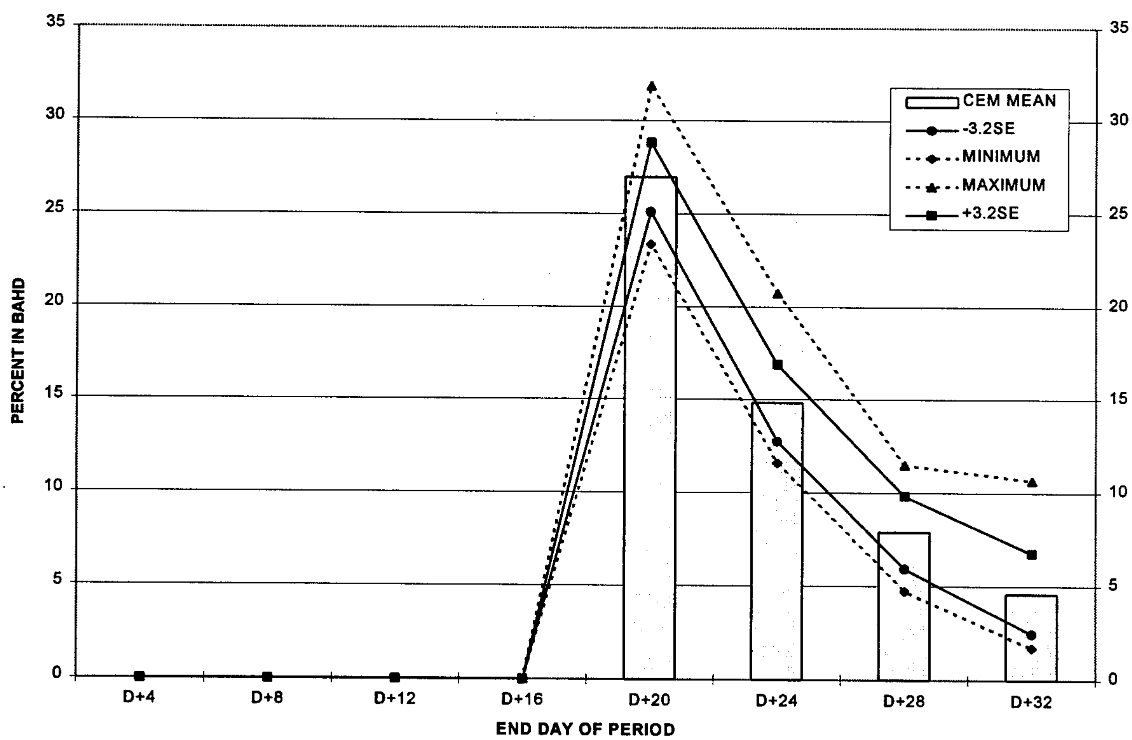


Figure 3-4. Percent of US/UK Committed STOCEM Force in Attack Posture Opposing a Prepared Defense in Each 4-day Period (base case scenario)

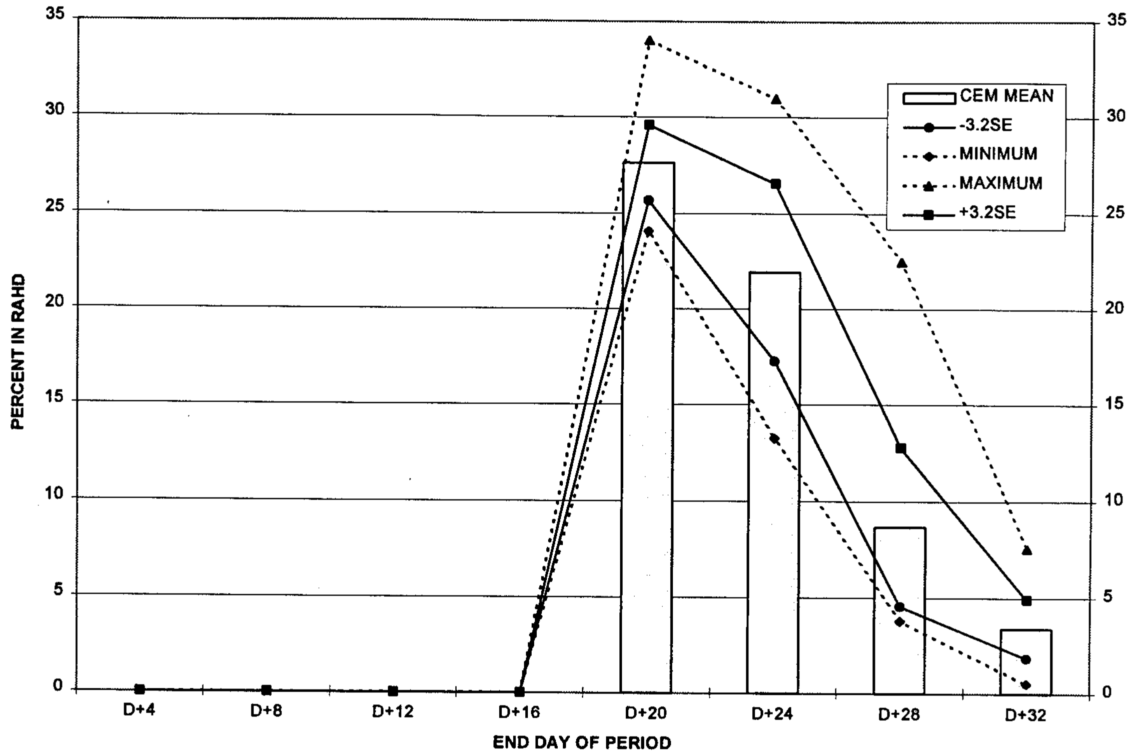


Figure 3-5. Percent of US/UK Committed STOCEM Force in Attack Posture Opposing a Hasty Defense in Each 4-day Period (base case scenario)

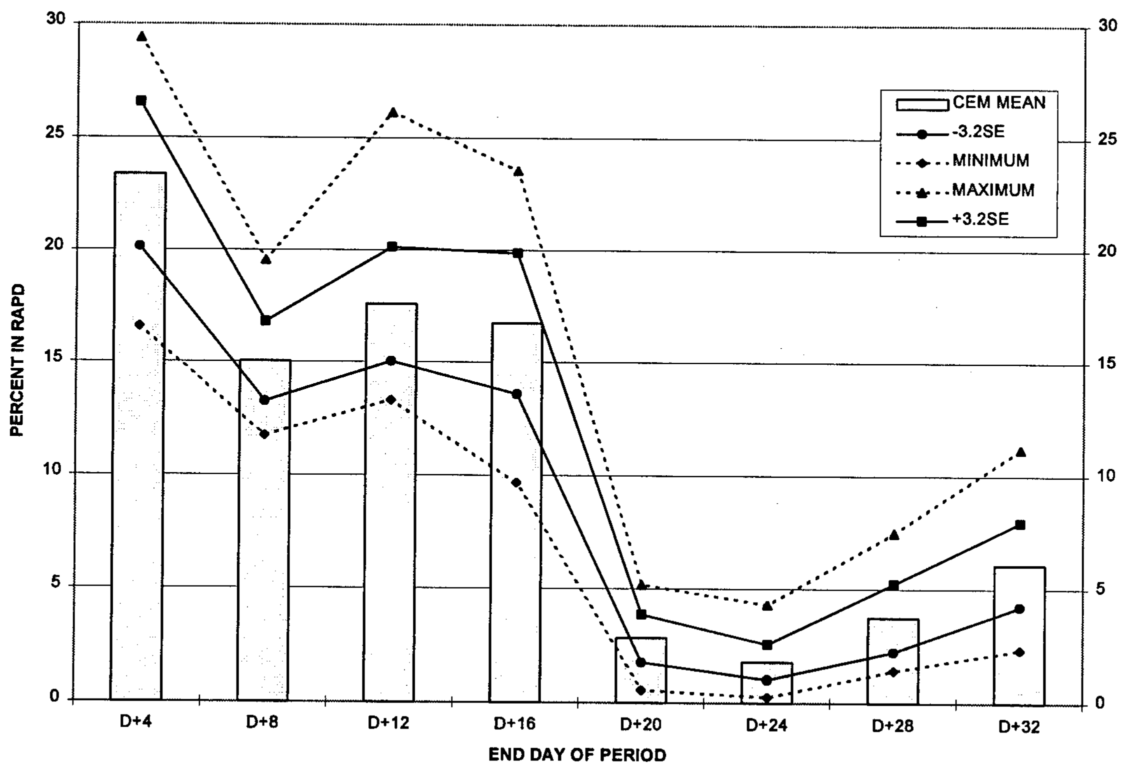


Figure 3-6. Percent of US/UK Committed STOCEM Force in Prepared Defense Posture in Each 4-day Period (base case scenario)

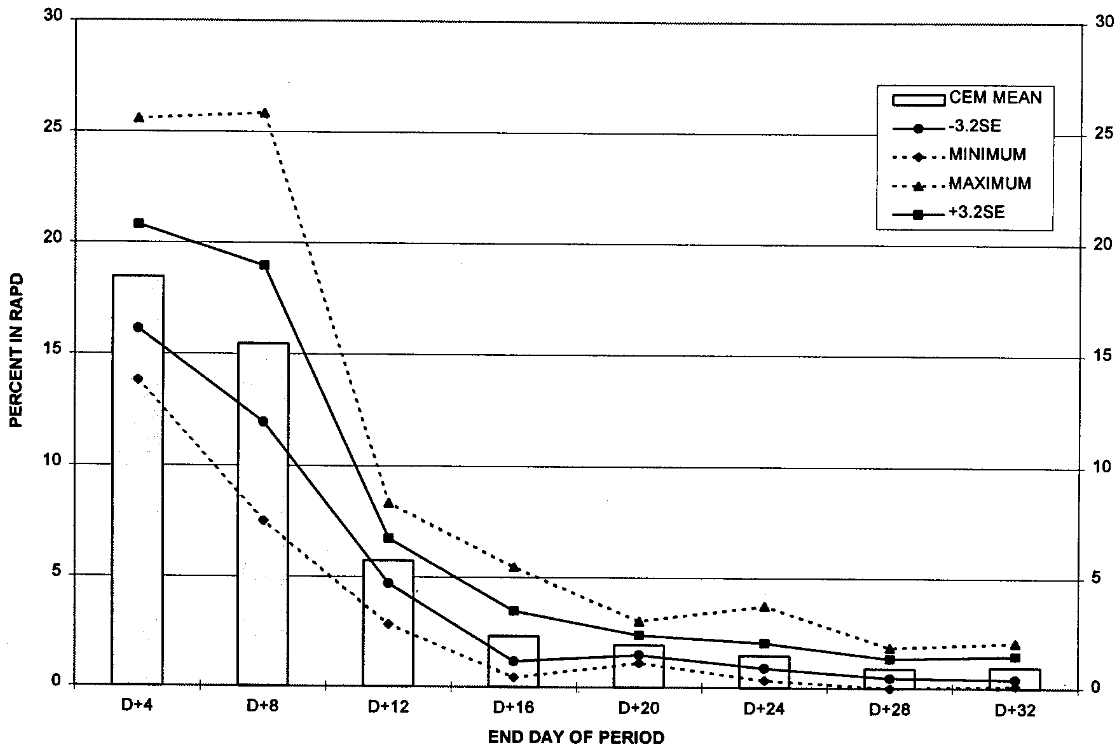


Figure 3-7. Percent of US/UK Committed STOCEM Force in Hasty Defense Posture in Each 4-day Period (base case scenario)

Since STOCEM combat activity is affected by engagement posture, information in these figures will be explicitly referenced as required during analysis of results in this as well as succeeding chapters.

3-3. UNCERTAINTY IN HISTORICAL FEBA POSITION. Figure 3-8 graphically illustrates the effect of uncertainty in the historical FEBA on D+8, as derived from the ACSDB, and quantified in paragraph 2-8, Chapter 2. A complete set of charts showing historical FEBA uncertainty at 4-day intervals is presented in Appendix E.

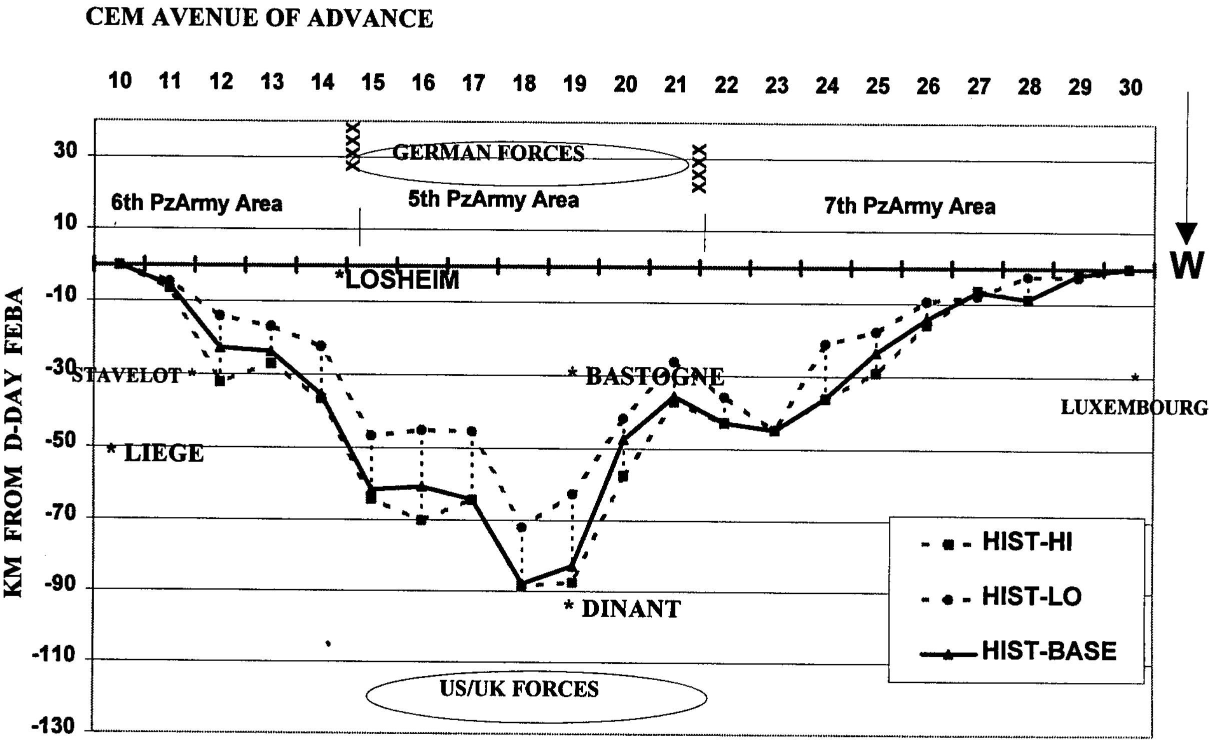


Figure 3-8. Uncertainty in Historical FEBA Positions on D+8

a. Format. The Base History FEBA on D+8, as defined previously, is plotted in Figure 3-8 for each of the 21 STOCEM avenues of advance, which are oriented as displayed in Figure 2-3 and indexed left-to-right in north-to-south order. The magnitude of the FEBA progress is plotted for each avenue of advance. The D-day position is at the 0 ordinate, and a negative "km from D-day FEBA" corresponds to a German advance. This linearized representation emulates a quasi-geography for the battle with relative positions along the (north-south ordered) STOCEM avenues of advance represented as parallel straight lines. The orientation is from an aerial perspective facing east from above US/UK lines. The upper and lower bounds for the ACSDB FEBA (the Hi History FEBA and Lo History FEBA defined in paragraph 2-8) are represented as the dashed lines in the chart. These form a band quantifying uncertainty in the ACSDB representation of the D+8 FEBA. A broken line shows the spread in this uncertainty for each avenue of advance. The Base History FEBA is the thick solid line graph. Only 21 points, one FEBA position for each avenue of advance, are plotted.

b. Assessment of Uncertainty. The largest spreads in uncertainty in Figure 3-8 are associated with the 5th PzArmy area, probably because that sector had the highest density of forces in the theater. Additional uncertainty, not shown in this chart, is likely to be present because the historical creators of unit records almost certainly were incomplete and inconsistent at times. Also, the interpolation/extrapolation methods used by the ACSDB contractor to fill time gaps in records generated estimates of indeterminate accuracy. Overall, charts such as this one show that "history" has significant uncertainty in its records. The Base History FEBA is treated here as a best estimator with a fixed (constant) value for comparisons with STOCEM, but the reader must always be aware of the "fuzziness" of its quantitative definition.

3-4. FEBA PROGRESS RESULTS. This paragraph compares a theater representation of the Base History FEBA on D+8 with both the STOCEM base case FEBA and the STOCEM excursion case FEBA on D+8. The D+8 FEBA corresponds to the "high water mark" (i.e., maximum advance) of the German offensive in the historical campaign. The D+8 analysis is followed by an assessment of average FEBA progress comparisons (history vs STOCEM base case or history vs STOCEM excursion case) assessed at 4-day intervals throughout the scenario. The complete set of theater representation plots of STOCEM base case FEBA progress vs history, STOCEM excursion case FEBA progress vs history, and STOCEM base case FEBA vs STOCEM excursion case FEBA, plotted at 4-day intervals throughout the campaign, are displayed in Appendix F.

a. Cartesian Representation of STOCEM Base Case vs History on D+8. Figure 3-9 compares the Base History FEBA with the STOCEM base case FEBA in a Cartesian (x-,y-) theater representation on D+8. The representation is exactly analogous to that of Figure 3-8. The vertical axis shows "km advanced from D-day positions" on each CEM avenue of advance, where these avenues are in a north-to-south ordering along the horizontal axis. Only one point is plotted in the figure for each measure on each avenue of advance. The lines connecting these points are added only to facilitate a visual comparison.

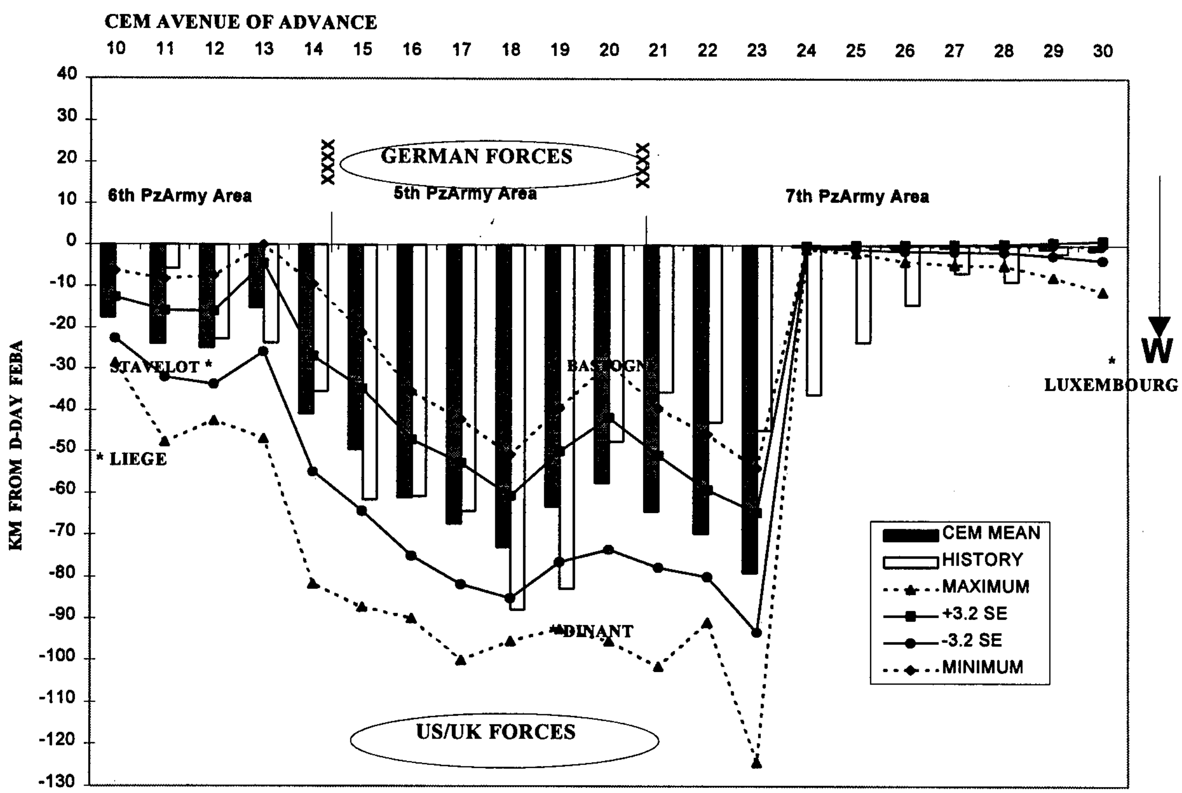


Figure 3-9. STOCEM Base Case FEBA vs History on D+8 (with uncertainty)

(1) The bars in the figure show:

(a) The average "km from D-day FEBA" STOCEM positions for each CEM avenue of advance. The CEM mean (average) FEBA represents the average position of the STOCEM FEBA over all 16 replications of the STOCEM base case on D+8. This was computed by finding the average D+8 FEBA position, over the 16 replications, on each STOCEM avenue of advance in the theater.

(b) The Base History FEBA position on each CEM avenue of advance in the theater, where the Base History FEBA is defined as in paragraph 2-8.

(2) The dashed line showing the CEM maximum FEBA represents the maximum westward advance of the STOCEM FEBA over all 16 replications of the STOCEM base case on D+8. This was computed by finding the westernmost D+8 FEBA position, over the 16 replications, on each STOCEM avenue of advance and connecting these "avenue maximum FEBA positions." The CEM maximum FEBA, as computed in this manner and represented on this figure, is a mathematical construct rather than a "real FEBA."

(3) The dashed line showing the CEM minimum FEBA represents the easternmost position of the STOCEM FEBA over all 16 replications of the STOCEM base case on D+8. This was computed by finding the easternmost D+8 FEBA position, over the 16 replications, on each STOCEM avenue of advance and subsequently connecting these "avenue minimum FEBA positions."

(4) The thin solid line graphs in the figure show the 99 percent/90 percent confidence limits for the average STOCEM FEBA on D+8 (99 percent limits under normality assumption, 90 percent limit if normality is not assumed). These are denoted as +3.2 SE and -3.2 SE in the chart because, statistically, they are separated from the STOCEM average by 3.2 standard errors. These two pairs of lines form bands which graphically portray the uncertainty in stochastic variation in the D+8 STOCEM FEBA.

b. Geographic Representation of STOCEM Base Case FEBA on D+8. Figure 3-10, generated by the Terrain Evaluation Module software tool, shows a digitized map representation of the Ardennes theater of operations at the end of D+8 (December 24, 1944) overlaid with the Base History FEBA and the STOCEM mean FEBA position, maximum FEBA position, and minimum FEBA position representing the STOCEM measures of dispersion. Figure 3-10 represents the "actual geographic" representation of the FEBAs shown in the Figure 3-9 Cartesian representation.

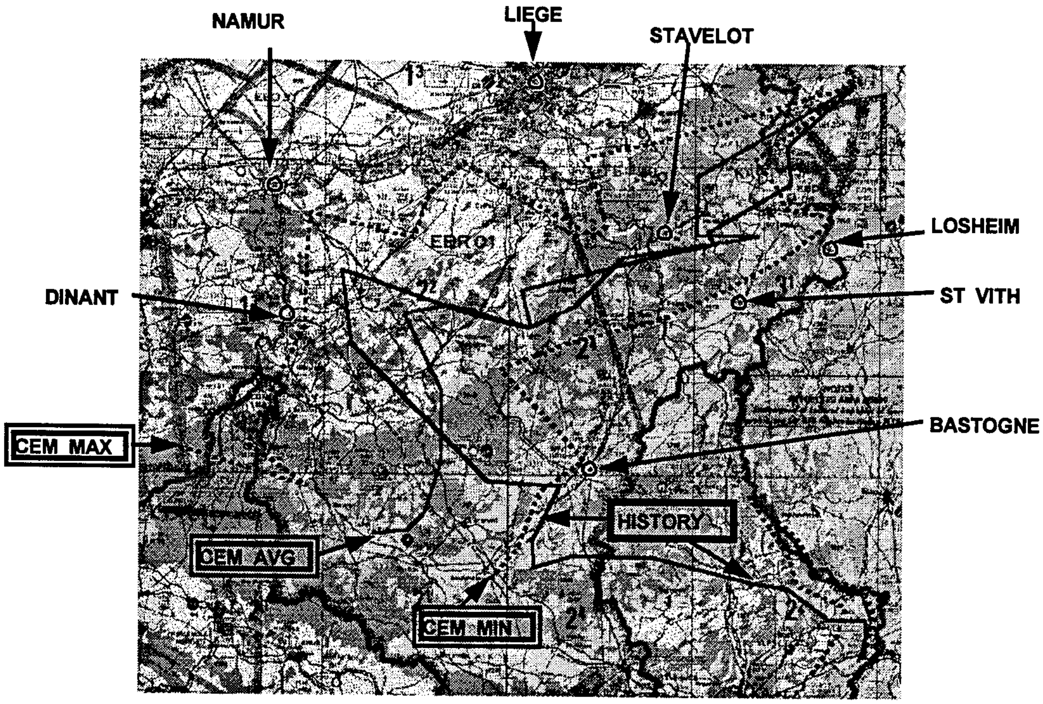


Figure 3-10. Map Display of STOCEM base case FEBA vs History on D+8

The discontinuities (breaks) in the CEM FEBA line on the southern area in the chart are exposed flanks which occur because the "bulge" and the nearly static situation in the far south (lower right in the chart) are in independent STOCEM sectors of operation (denoted as "CEM Armies" in STOCEM). The STOCEM excursion case, as will be shown subsequently, did not have such exposed flanks because the STOCEM excursion case theater was a single sector of operations. In the excursion case, reinforcing units could be placed by STOCEM anywhere in the theater, whereas the STOCEM base case conformed more closely to history by limiting reinforcements to their historical Army areas.

c. Comparison of STOCEM Base Case with History on D+8. Although the History FEBA is not always within the STOCEM confidence limits in Figure 3-9, the historical "bulge" is clearly very similar to the STOCEM "bulge" in the 5th Panzer Army Area (avenues of advance 14 through 21). The most noteworthy deviation is the nearly complete lack of any STOCEM advance in the seven southernmost (rightmost on the chart) avenues of advance. This contrasts with the small historical advances that increase in magnitude for forces nearing the southern boundary of the "bulge." In the geographic representation of Figure 3-10, the STOCEM average FEBA clearly shows a configurational similarity to the historical "bulge." Especially noteworthy is the similarity in the position of the "spike" pointing toward Namur in both the STOCEM and historical FEBAs.

d. Average STOCEM Base Case FEBA Progress Over Time. Figure 3-11 graphically portrays the progress of the average STOCEM base case FEBA at 4-day intervals and contrasts it with the average Base History FEBA. The line graphs in the figure show average FEBA progress (STOCEM and history) for the entire theater. The bar graphs in the figure show FEBA progress for only 5th Panzer Army area, which comprised most of the historical "bulge." The average FEBA progress for the theater on a day is defined as the simple arithmetic average of the FEBA progress on each CEM avenue of advance in the theater. The average FEBA progress for the 5th Panzer Army area on a day is defined analogously except that the average is only over the avenues of advance in the 5th Panzer Army area (avenues 14 through 21).

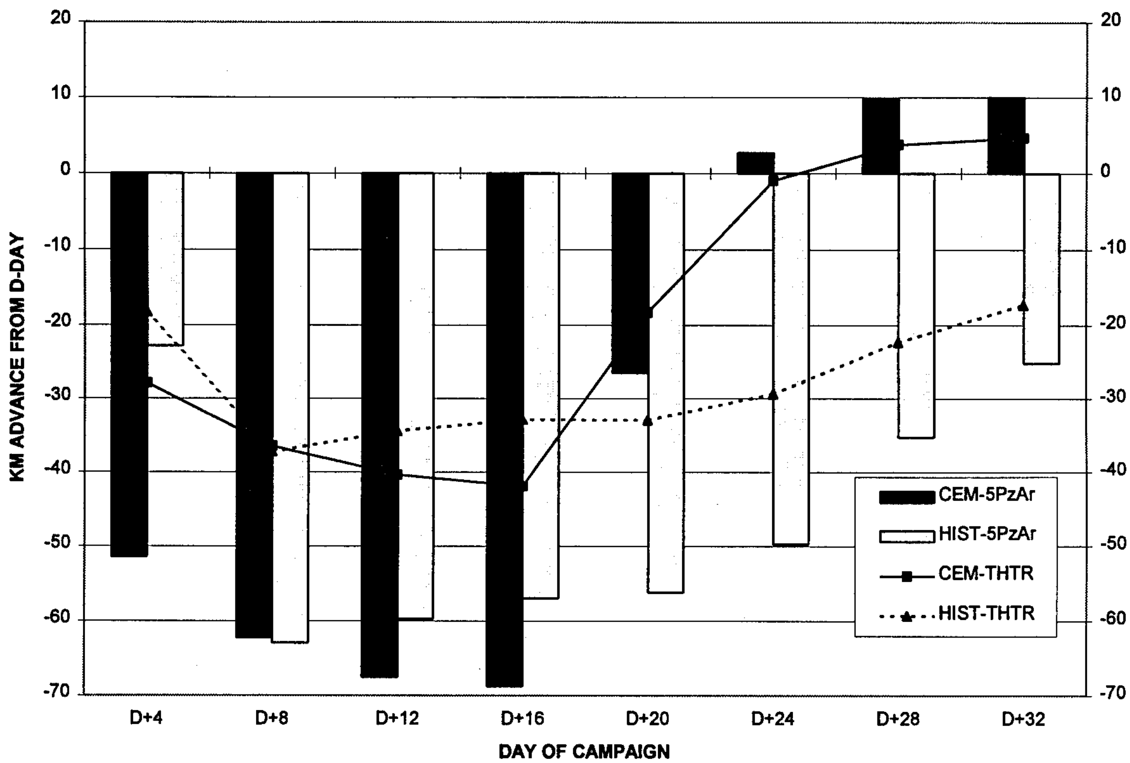


Figure 3-11. Average FEBA Progress Over Time in Theater and in 5th Panzer Army Area (STOCEM base case)

From the chart, it is apparent that, on average:

(1) The initial German advance in STOCEM is much more rapid than history (50 km through D+4 vs an historical 23 km).

(2) After D+4, STOCEM is very similar to history through D+16.

(3) After D+16, the counterattacking US/UK force in STOCEM makes the Germans retreat at a considerably more rapid rate than occurred historically.

(4) The most rapid US/UK advance in STOCEM occurs 8 days ending in D+24 when the US/UK force has the largest fraction of its committed force in the attack posture. From Figure 3-2, over 50 percent of the US/UK force is attacking during the period ending in D+20 and almost 40 percent are attacking in the period through D+24 . In addition, Figure 3-5 showed that the 8 days ending in D+24 also have the largest fraction of the US/UK committed force opposing a German prepared defense.

(5) The differences in the theater averages behave in a manner very similar to the 5th Panzer Army averages.

The average STOCEM US/UK advance stops at approximately 10 km past the D-day positions because the STOCEM scenario used the D-day positions as a final objective for the (counter) attacking US/UK force. Each STOCEM US/UK unit in the scenario assumes a permanent static posture as soon as a movement status check, made every 12 (game) hours, shows it as having passed its final objective. Movement past the D-day objective occurs during the (up to 12-hour) period just before the status check recognizing achievement of the objective.

e. **Effect of Uncertainty on Average FEBA Advance Over Time.** Figures 3-12 and 3-13 include measures of stochastic uncertainty around the average STOCEM FEBA progress over time charted in Figure 3-11. Figure 3-12 shows average FEBA progress over the entire theater while Figure 3-13 shows it only over the 5th Panzer Army area. The History FEBA and STOCEM mean FEBA shown on these figures are the same results as are shown in Figure 3-11. In addition to the average STOCEM FEBA, these figures also show the four measures of STOCEM uncertainty defined in paragraph 2-7 and used earlier in Figure 3-9. The solid lines labeled +- 3.2 SE are the 99 percent/90 percent confidence limit bounds for the STOCEM average FEBA.

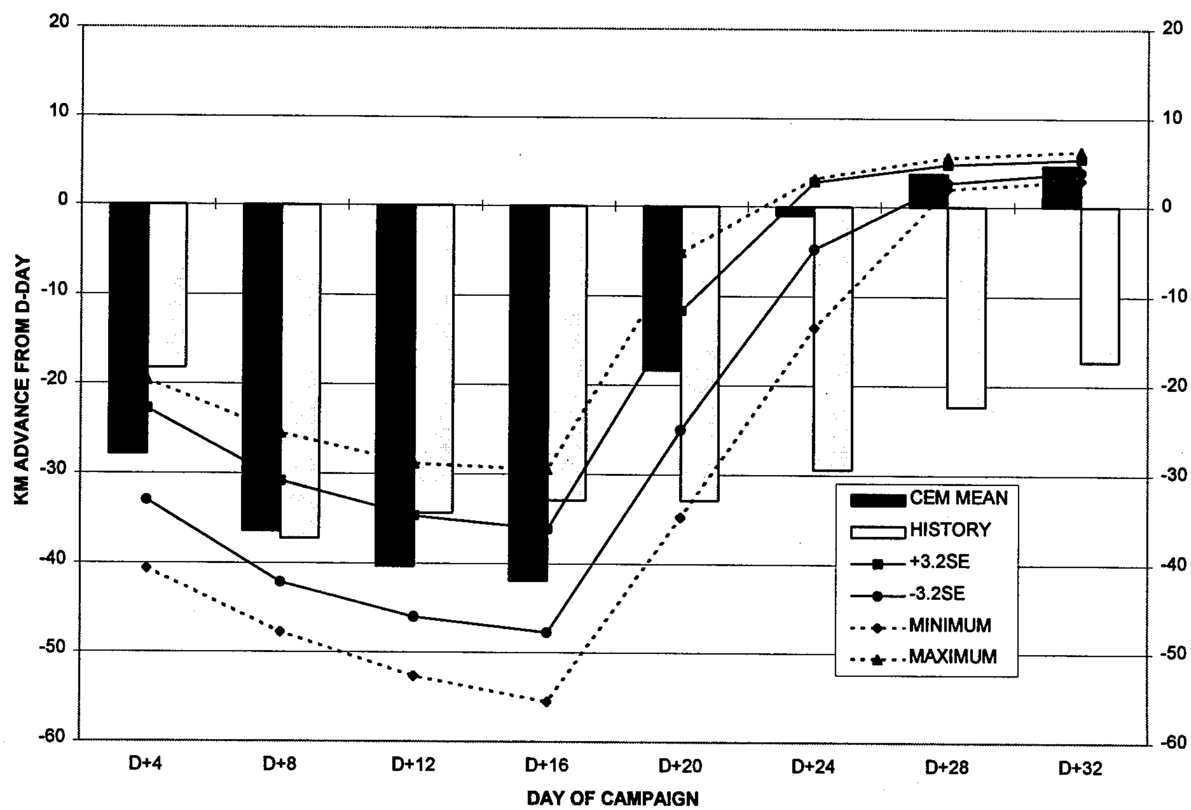


Figure 3-12. Average Theater FEBA Progress with Uncertainty (STOCEM base case)

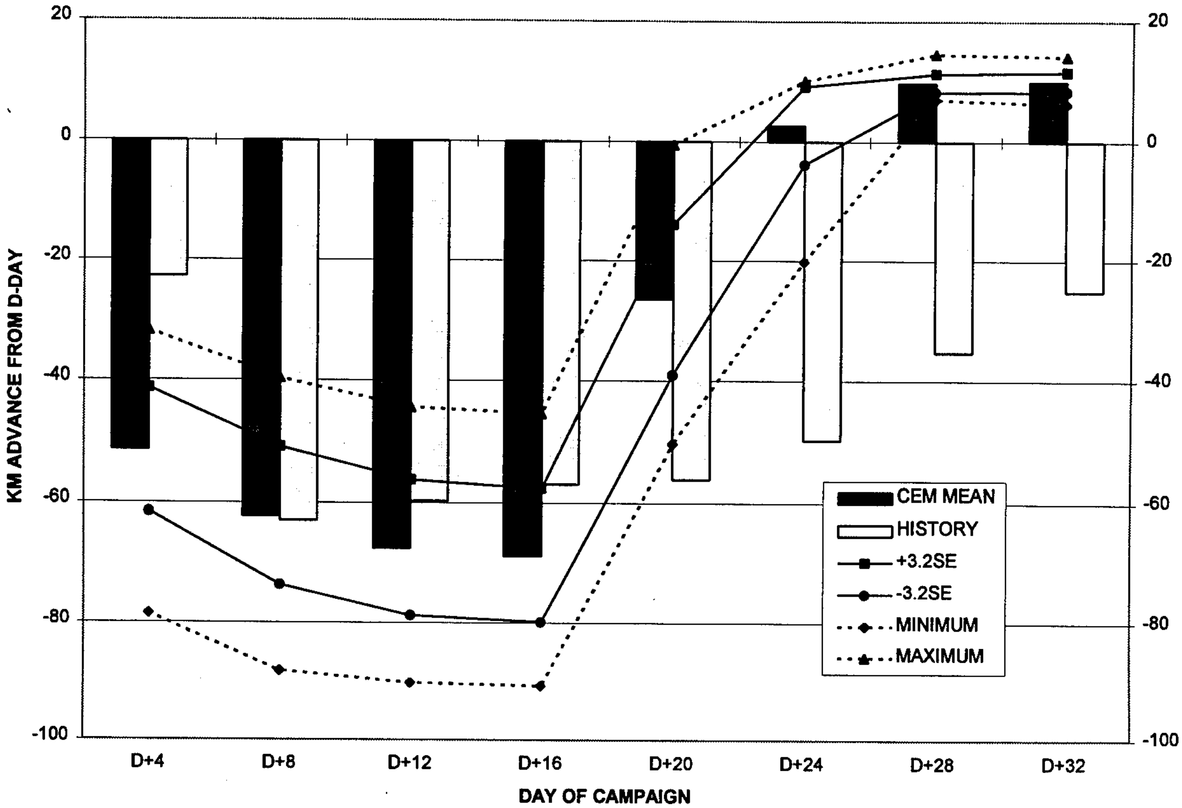


Figure 3-13. Average 5th Panzer Army Area FEBA Progress with Uncertainty (STOCEM base case)

Although the observations noted from Figure 3-11 also apply here, these figures show the considerable variation in STOCEM FEBA results. This variation decreases considerably during the last week in the campaign because the STOCEM US/UK force assumed a permanent static posture within 12 hours after it reached the D-day objective positions (which correspond to 0 km advance from D-day on the chart).

f. STOCEM Base Case versus STOCEM Excursion Case

(1) FEBA Snapshot on D+8. Figures 3-14 and 3-15 compare the STOCEM base case scenario mean FEBA with the STOCEM excursion case mean FEBA and with the Base History FEBA on D+8. Figure 3-14 compares average km progress on each CEM avenue of advance, while Figure 3-15 is a geographic representation in a digitized map similar to Figure 3-10.

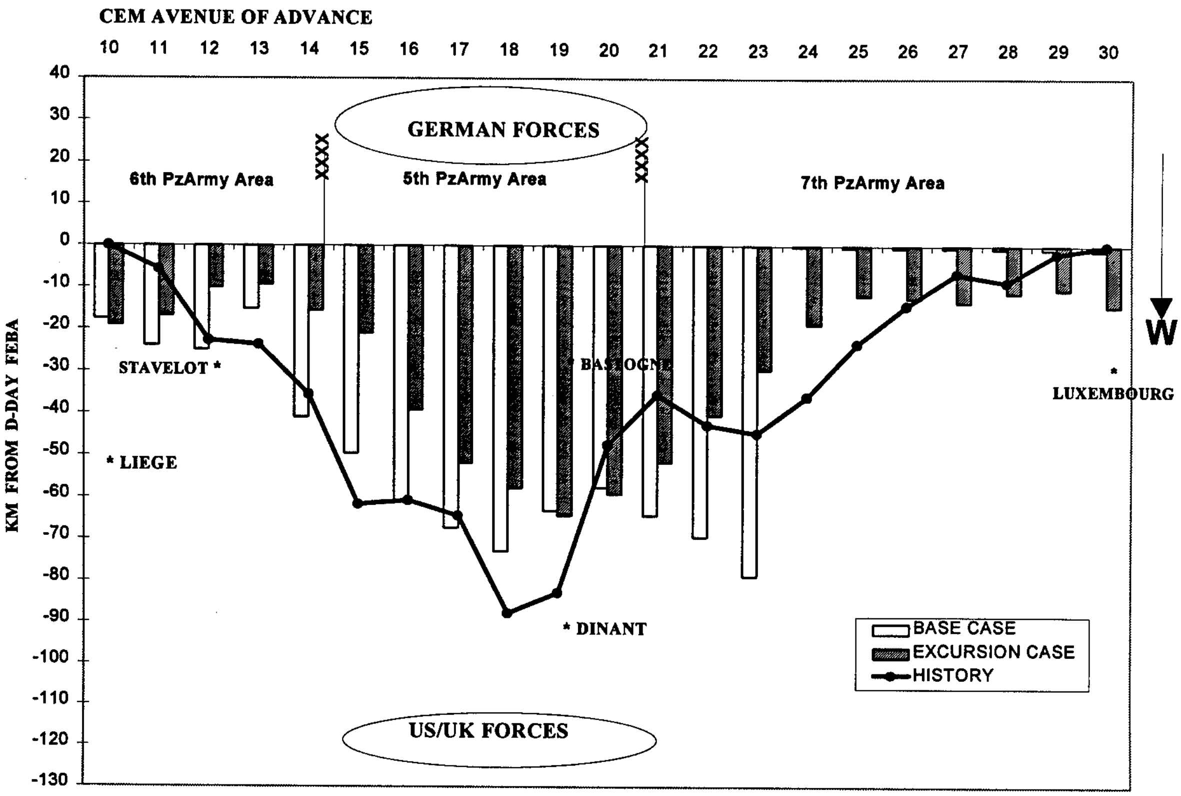


Figure 3-14. Linear FEBA Progress Comparison on D+8 (STOCEM base case vs STOCEM excursion case)

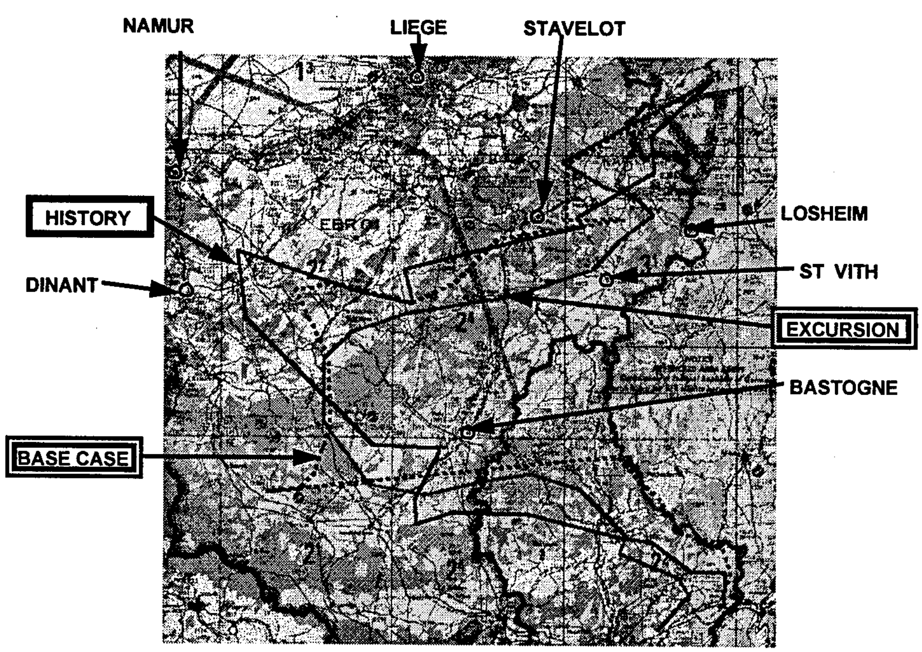


Figure 3-15. Map Display of FEBA Progress Comparison on D+8 (STOCEM base case vs STOCEM excursion case)

The figures show the STOCEM excursion case making considerably less progress in the bulge than does the STOCEM base case while advancing further outside of the bulge. Outside of the bulge, the excursion case FEBA here conforms more closely to history than does the STOCEM base case. Recall that the STOCEM excursion case treated the theater as a single sector of operation in which reinforcing units could be placed by CEM anywhere in the theater, while the STOCEM base case limited reinforcements to their historical army areas. In the STOCEM excursion case, the German attack seems to have been somewhat "evened out" relative to the STOCEM base case. The base case specified, through input conforming to history, the concentrating of German forces in the bulge. These figures support the following observations:

(a) Observation 1. The STOCEM excursion case, by its definition, could concentrate attack forces in any region of the theater; it was not "forced" to concentrate on the bulge. The fact (observed in these figures) that it chose to concentrate its attack in the historical bulge lends credibility to the STOCEM simulation model as a tool for prediction and analysis.

(b) Observation 2. The bulge in the STOCEM excursion case makes less progress than the STOCEM base case. This is consistent with history being represented by the base case because, historically, the Germans concentrated forces so that maximum progress was made in the bulge. This result lends credibility to the STOCEM base case representation of this German plan.

(c) Observation 3. Since the STOCEM excursion case was somewhat omniscient in its open-ended reinforcement allocation policy, it should show less German FEBA success on D+8 than the STOCEM base case, reflecting the historical US/UK reinforcement policy which was less than omniscient. The above figures show this to be the case. The comparison lends credibility to the value of the STOCEM combat simulation as a useful planning and forecasting tool.

(d) Observation 4. The bulge in the STOCEM base case average FEBA shows a distinct configurational similarity to the historical bulge. Especially noteworthy is the similarity in the position of the spike pointing toward Namur in both the STOCEM and historical FEBAs. This reproduction of significant aspects of an actual campaign supports the usefulness and realism of model dynamics in STOCEM. (Recall that the model was not "tuned" by varying parameters through trial and error until a specific desired result was achieved.)

(2) Average FEBA Progress Over Time. Figure 3-16 compares the average STOCEM base case FEBA progress over time with the STOCEM excursion case mean FEBA progress. Averages are shown for both the entire theater and for the 5th Panzer Army area.

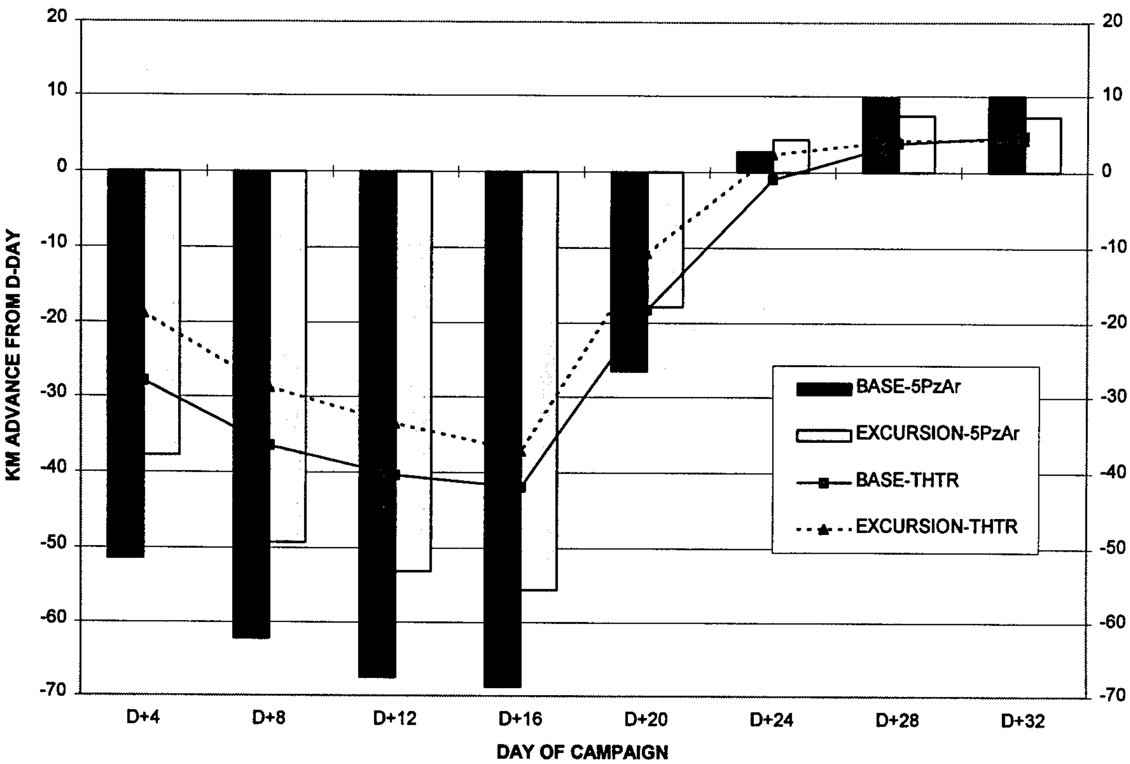


Figure 3-16. Average FEBA Progress Over Time (STOCEM base case vs STOCEM excursion case)

The figure shows the STOCEM excursion case making consistently less progress than the STOCEM base case in both the theater and in the 5th Panzer Army area, which comprises the bulge. The differences (between base case progress and excursion case progress) are largest during the first half of the campaign and diminish thereafter. This is due to the STOCEM movement being halted after the D-day positions are reached in the advance. During the first half of the campaign, the average difference in FEBA progress between the two cases over the 5th Panzer Army area (the bulge) is almost double the average difference (7 km) over the entire theater. The overall trends of average FEBA progress over time appear to be very similar in the two cases.

3-5. OBSERVATIONS ON FEBA PROGRESS RESULTS. This paragraph summarizes observations on the FEBA results described above and provides supplemental rationale.

a. The bulge in the STOCEM base case average FEBA for D+8 shows a distinct configurational similarity to the historical bulge both in extent and area.

b. The STOCEM excursion case average FEBA on D+8 was also similar to the historical outcome, especially in the area outside of the bulge. STOCEM in the excursion case also concentrated its attack in the historical bulge even though it was not "forced" to concentrate forces in that region of the theater. (Its reinforcement policy could concentrate attacking forces in any region of the theater.) These results increase the credibility of the STOCEM simulation mechanism and logic

c. The STOCEM base case FEBA penetrated further than the STOCEM excursion case FEBA. Such a base case German advantage reflects the expected result of credible combat logic representing actual history because the omniscience of the US/UK reinforcement policy associated with STOCEM representation in the excursion case was not present in actual history. The surprise factors in the historical German Ardennes Campaign gave an advantage to the Germans. The absence of this advantage in the STOCEM excursion case decreased the effectiveness of the German attack (relative to the base case). The STOCEM base case reflects the historical (nonomniscient) allocation of reinforcements.

d. From Figures 3-11, 3-12, and 3-13, it is apparent that, on average, STOCEM advances too rapidly (relative to history) in the first 4 days and, after D+16, the counterattacking US/UK force induces a German retreat with a considerably faster retrograde movement than occurred historically. From Figure 3-11, the most rapid STOCEM rollback occurred during the periods (D+16 through D+24) when the fraction of US/UK force in attack posture was largest and when the portion of that force attacking a prepared defense is largest. The most rapid STOCEM German advance occurred in the first 4 days when, according to Figure 3-6, the fraction of the force in a prepared defense posture was largest for the defending US/UK force. Possible reasons for these deviations include:

(1) The move rate inputs used by STOCEM were too high, especially for movement in attack posture. The model's input rates reflect a "steady state" potential movement capability for a force actively engaged in a specified posture. However, real combat movement never continually achieves its potential, due to tactical, weather, and logistical considerations that are not explicitly modeled by STOCEM. In the historical campaign, adverse weather conditions and the poor state of roads often degraded move rates to levels well below optimum potential. The ARCAS results indicate that the STOCEM move rate inputs need to be decreased in magnitude to reflect additional tactical, weather, and logistical constraints implicit in actual combat, but which are not explicitly modeled.

(2) The placement and concentrations of forces generated by a fully automated simulation model, such as STOCEM, may well achieve a stronger rollback of a weaker opponent than can be achieved by a less efficient and more constrained actual force. An actual combat force deploys its units less effectively than a computer model and, affected by human factors reflecting "real world" uncertainty, moves with more caution and deliberation than is reflected in its potential. The STOCEM logic consistently reinforces and exploits success in attack with relentlessly consistent and efficient algorithmic rules, unlike decisions and actions in "real life." Actual combat movement, as shown in ARCAS results, usually consists of a graduated advance reflecting a "grinding down" of the enemy rather than a continual "blitzkrieg." This "grinding down" continues to be evident in historical ARCAS results even as the US/UK strength advantage increases while the campaign progresses. STOCEM, on the other hand, continually uses "perfect intelligence" during the simulated campaign to determine how and where to concentrate superior forces so as to make and execute a maximally effective "combat punch," resulting in a near-optimum force advance. An actual combat force deploys its units less effectively than a computer model and, affected by human factors reflecting "real world" uncertainty, moves more carefully and cautiously than its potential. The greater the attacker strength advantage, the greater will be the difference between the force movement produced by computer algorithms with unbridled efficiency and aggressiveness and the graduated movement of actual combat. Consistent with this, the largest ARCAS movement differences (between STOCEM and history) are in the first few days of the campaign, when the German strength advantage was greatest, and after D+16, when the US/UK was attacking with an ever-increasing strength advantage.

e. In 1973, SHAPE Technical Centre (STC) contracted work to derive, from historical data, a predictive stochastic relationship for movement and casualties of engaged forces. The result (Ref. 8) used a historical data set of brigade through division attacks which occurred during the 1944-45 Ardennes Campaign. Multiple regression was used by the contractor to derive predictive equations. Subsequent analysis of these equations by STC was limited to those predicting opposed movement. Results of that analysis (Ref. 9) indicated that:

(1) Defender posture and degree of attacker mechanization are the most significant contributors to force advance.

(2) Highly mechanized attacks against prepared defenses produce sustained attacker advances that are significantly less than those produced by the STC version of the ATLAS theater combat model.

The observations noted in paragraph 3-5d tend to support the above observations, as applied to ARCAS STOCEM (instead of the STC ATLAS model).

3-6. RECOMMENDATIONS FOR IMPROVING STOCEM LOGIC

a. Moderation of Movement in a Sustained Attack/Advance. The results showing average STOCEM FEBA progress over time are consistent with a combat model that, once it goes on the attack, does not "pause for breath." A reasonable hypothesis, supported by the ARCAS historical results, is that a sustained rapid force advance is often punctuated by intervals of reduced mobility and aggressiveness due to tactical and logistical constraints, caution in the face of uncertainty, and the need to regroup to conserve the integrity of its organization. STOCEM does not appear to simulate this tendency to a sufficient degree. Therefore, a possible improvement in STOCEM logic to better reflect this would be an algorithmic moderation of move rate in response to a "sufficiently sustained" rapid combat advance. One possible approach to this is for STOCEM to perform the following assessment on each engaged force component before movement is simulated in each 12-hour division cycle:

(1) Assess whether this engaged force component is in attack posture during this cycle.

(2) If the component is not in attack posture, make no changes; otherwise, assess how long this force component has been in attack posture. Specifically assess the consecutive 12-hour cycles (ending in this one) that this force component has been attacking.

(3) Reduce the "standard" CEM-calculated move rate in proportion to the duration that this force component has been in attack posture.

The above would moderate FEBA movement after the first cycle in attack posture. However, even that first cycle for the US/UK force in this scenario had a much larger rate of movement than history. Therefore, consideration should be given to also reducing the basic CEM input move rates of attacking units.

b. Fixing Force Closure on an Objective. Although STOCEM was programmed to treat the D-day positions as a final objective, the advancing US/UK force actually moved, on average, 5-10 km beyond the objective before stopping. This occurs because each STOCEM US/UK unit in the scenario assumes a permanent static posture only after a movement status check, made every 12 (game) hours, shows it as having passed its final objective. Movement past the D-day objective occurs during the (up to 12-hour) period just before the status check recognizing achievement of the objective. It seems more nearly correct and appropriate if each STOCEM unit can be programmed to stop at the objective positions. Ways to accomplish this should be devised and tested.

CHAPTER 4

ANALYSIS OF AMMUNITION EXPENDITURE RESULTS

4-1. INTRODUCTION. The purpose of this chapter is to portray and compare the simulation and historical results for expenditure of ammunition during the course of the Ardennes Campaign. Cumulative STOCEM and historical total ammunition consumption is depicted for each force. Comparison of STOCEM with history is used to develop observations impacting on simulation validation and recommendations for reevaluating selected CEM input factors.

4-2. AMMUNITION EXPENDITURE RESULTS

a. US/UK. Figure 4-1 shows base case STOCEM and historical cumulative (since STOCEM D-day of 16 December 1944) total tons of US/UK ammunition expended. Figure 4-2 shows the excursion case STOCEM and historical cumulative (since D-day) total tons of US/UK ammunition expended. Values in both figures are plotted at 4-day intervals. In addition to the STOCEM average value, the figure shows, in the style of Figure 3-9, four measures describing STOCEM uncertainty, viz., the STOCEM maximum and minimum and the 99 percent/90 percent confidence limits (denoted as +3.2 SE and -3.2 SE in the chart). These two pairs of lines form bands which graphically portray the uncertainty in stochastic variation in each cumulative ammunition expended.

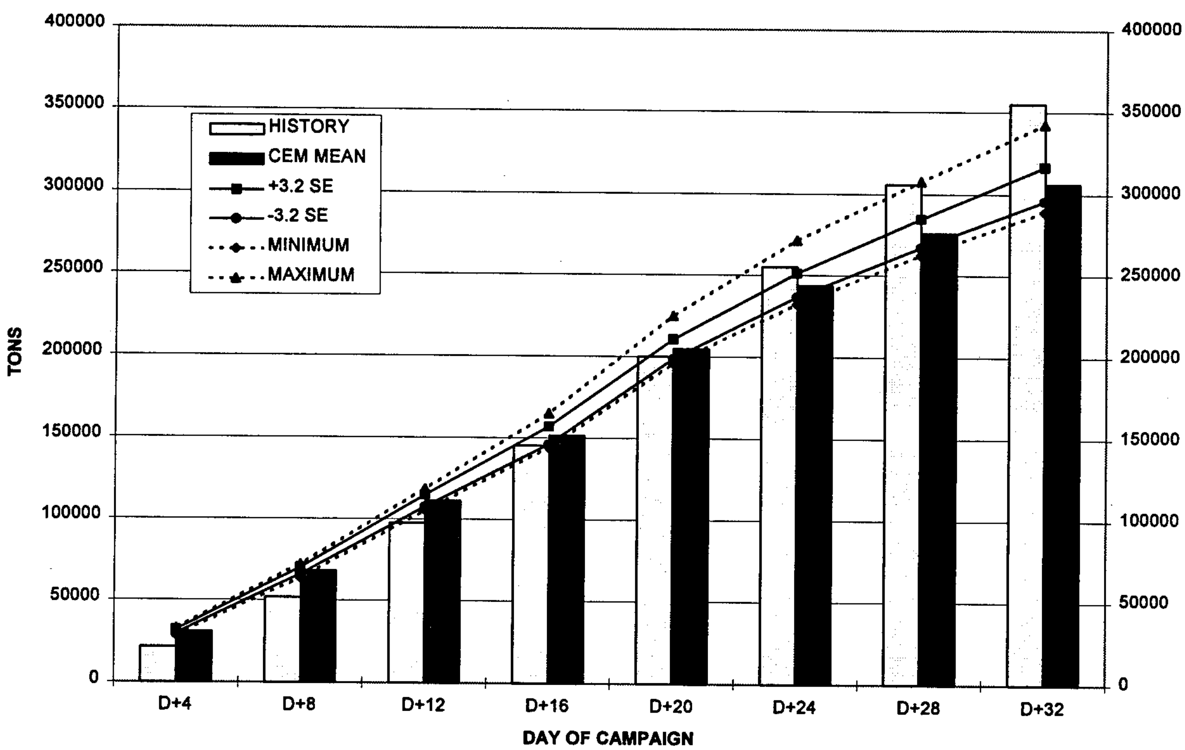


Figure 4-1. Cumulative US/UK Ammunition Tonnage Expended (STOCEM base case)

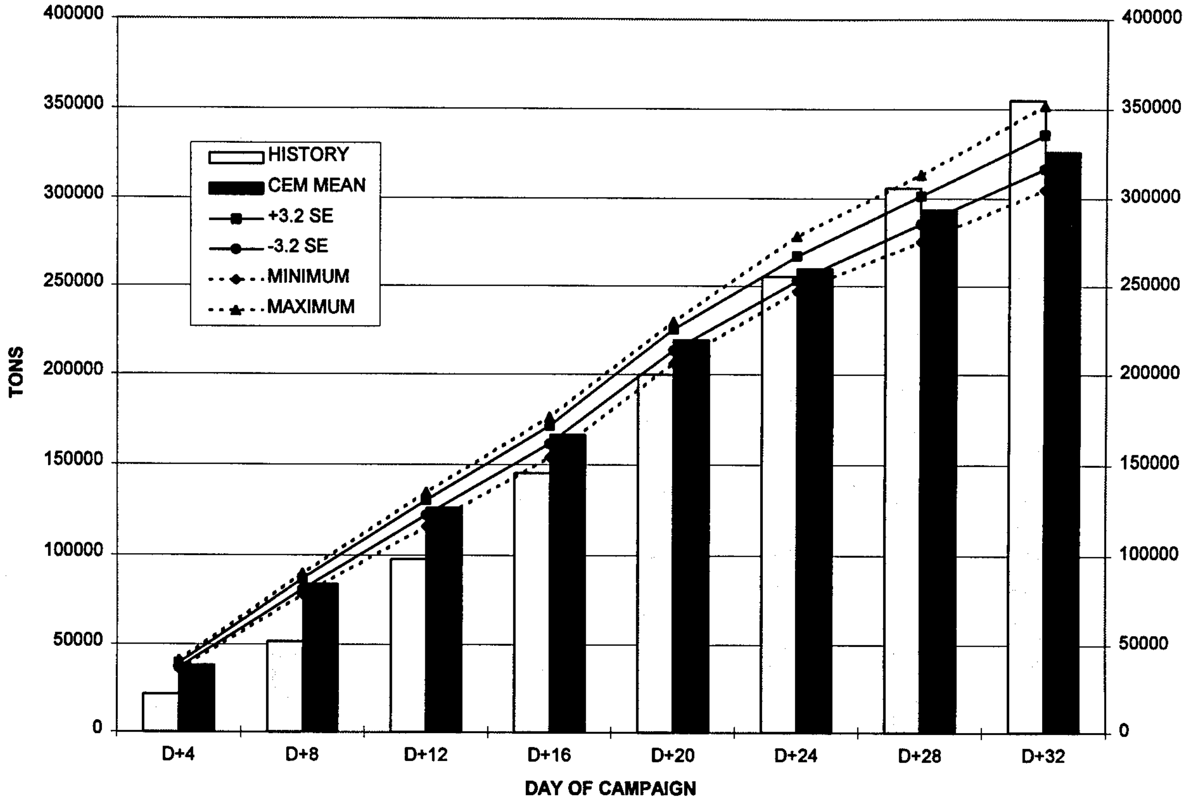


Figure 4-2. Cumulative US/UK Ammunition Tonnage Expended (STOCEM excursion case)

b. German. Figure 4-3 shows base case STOCEM and historical cumulative (since D-day) total tons of German ammunition expended. Figure 4-4 shows the analogous STOCEM excursion case results.

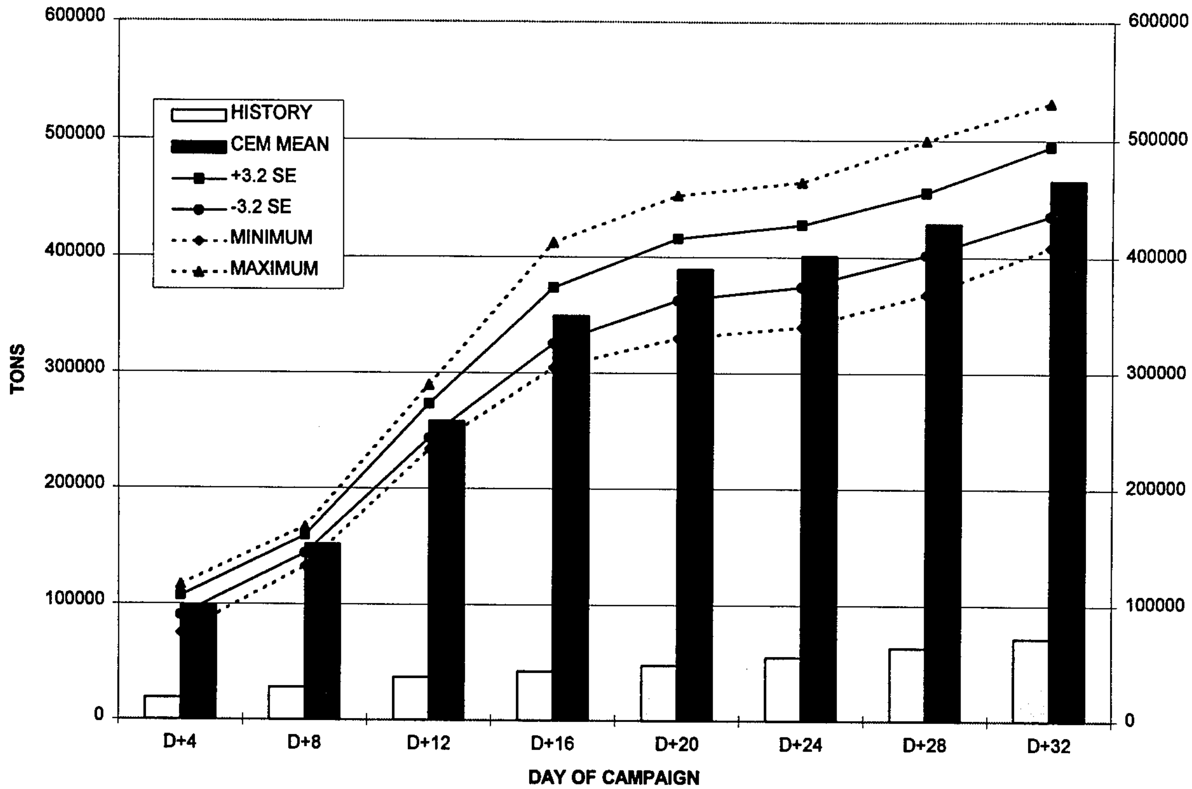


Figure 4-3. Cumulative German Ammunition Tonnage Expended (STOCEM base case)

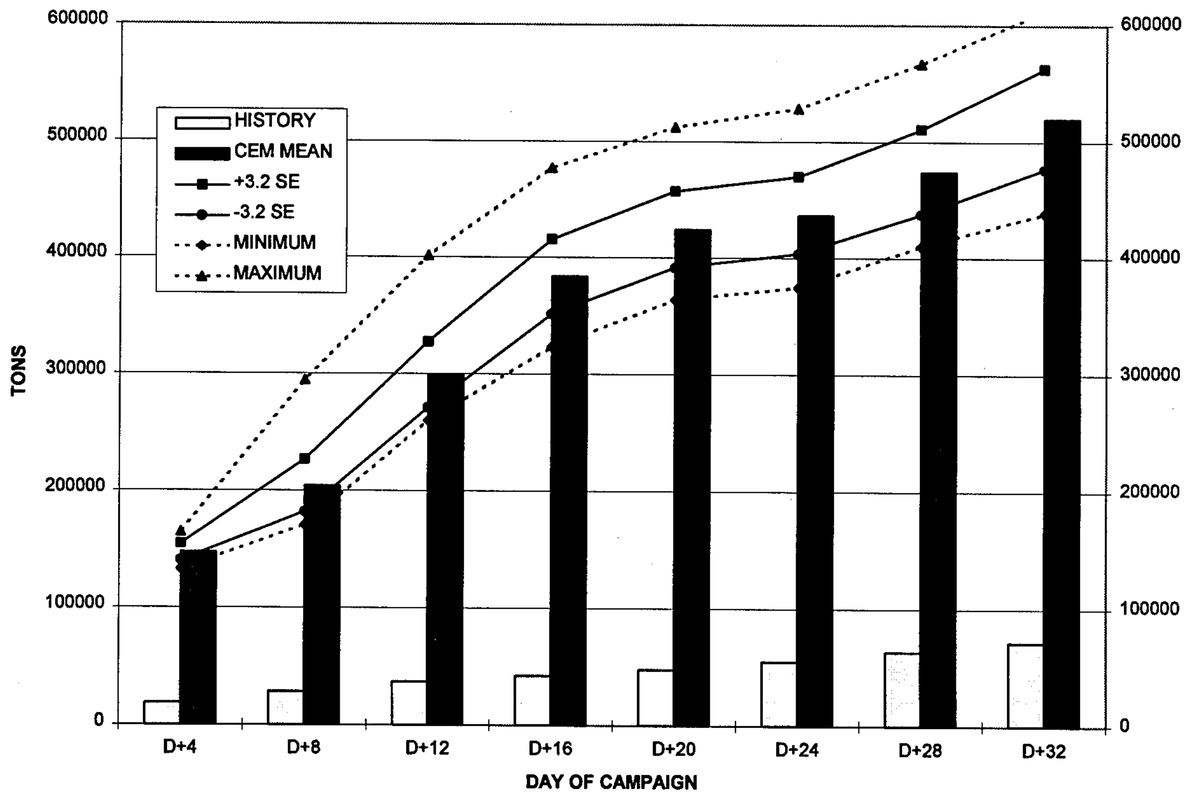


Figure 4-4. Cumulative German Ammunition Tonnage Expended (STOCEM excursion case)

4-3. OBSERVATIONS ON AMMUNITION EXPENDITURE

a. US/UK Expenditure. STOCEM results in the base case are similar to historical in both trend and magnitude, especially over the first 28 days of the campaign. From D+16 through D+28, the historical results are within the maximum/minimum limits of the base case STOCEM uncertainty bands. Cumulative base case STOCEM consumption at D+24 is only 4 percent less than historical. Thereafter, the difference increases until, at D+32, base case STOCEM expenditure is 14 percent less than historical. These similarities support the credibility of the STOCEM representation of US/UK ammunition expenditure. Additional observations include:

(1) The narrowness of the STOCEM uncertainty bands indicates that variability in STOCEM ammunition expenditures is proportionately much less than the variability in STOCEM FEBA results (as depicted in Figure 3-9).

(2) The STOCEM scenario caused the counterattacking US/UK force to go into a static posture once the D-day positions were crossed. Depending on location in theater, this shift to static posture occurred at approximately D+24. Ammunition expenditure in static posture is lower than in other more active postures. This probably explains the increasing shortfall in expenditure (relative to history) after D+24.

(3) STOCEM ammunition expenditure in the excursion case is higher than in the base case, especially in the first 12 days of the campaign. This increase is plausible, since reinforcing units in the excursion case are allocated to the "neediest" sectors in theater, where they would likely confront more opposition (and targets) than in the base case which restricted reinforcing units to their historically supported sectors. The differences are credible.

b. German Expenditure. STOCEM, in absolute terms, uses much more ammunition than history. This can be due to a number of considerations, including:

(1) During the historical Ardennes Campaign, the German ammunition transport and resupply was severely degraded by logistical problems, even though they had large ammunition stockpiles in their rear areas. A major component of the logistical problem was congestion on the roads leading to the German front, as well as a general shortage of trucks and other vehicles used to transport supplies, including ammunition. The historian Trevor N. Dupuy (Ref. 10) writes:

"... the German logistical transportation system was not up to the task. Using the rail lines available, it was simply impossible to move combat units forward and at the same time to assemble the stocks of fuel, ammunition, and other supplies required for the offensive."

He also notes that many artillery battalions were short of transport and therefore had trouble bringing up ammunition. This problem became worse as attacking units moved beyond the range of their nondivisional supporting artillery. These limitations were not modeled in the STOCEM scenario. STOCEM German ammunition expenditure would therefore be expected to be considerably larger than historical usage because it reflects unrealized potential expenditures rather than the severely constrained amount employed in the historical campaign.

(2) Part of the difference may be due to overestimation of single round ammunition weight in STOCEM inputs. Ambiguity in the definition of the input "ammunition weight" could account for substantial differences from historical records. For example, weight of ammunition can vary substantially depending on whether packing/pallet material is included. If the ratio of history expenditure/STOCEM expenditure on D+32 in Figure 4-3 (= .154) is used to multiplicatively adjust the magnitudes of all STOCEM expenditures, then Figure 4-3 is transformed into the pattern of adjusted ammunition expenditures shown in Figure 4-5. These adjusted expenditures reflect the result of a correction for a (hypothetical) STOCEM overestimation in single round weight inputs by a constant factor of 6.51. Historical and STOCEM German cumulative ammunition expenditures are very similar, in both magnitude and trend, after applying this constant multiplicative scaling adjustment to STOCEM ammunition round weight inputs. As in the US/UK cases, the STOCEM excursion case uses more ammunition, especially in the first 4 days of the campaign.

c. Recommended STOCEM Examination/Modification. The input German ammunition expenditure factors and round weights should be reevaluated to determine whether revised and corrected weights will generate scenario expenditure results closer to historical.

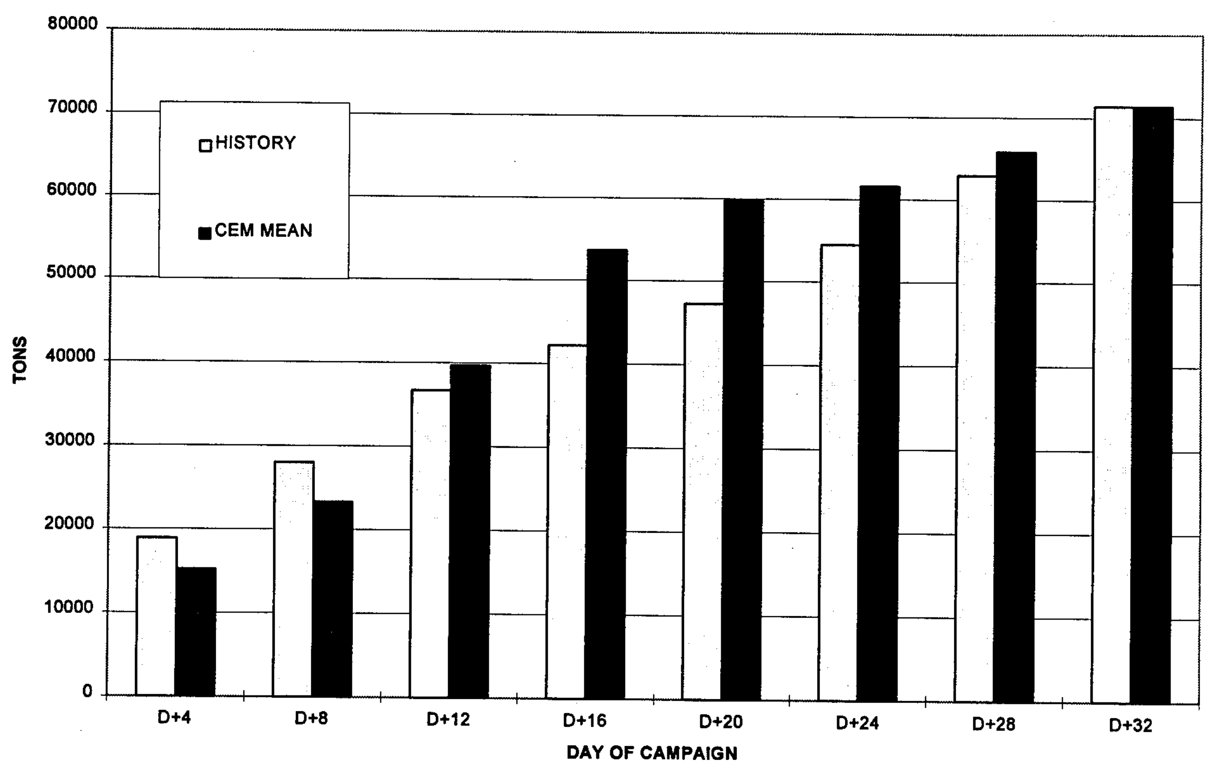


Figure 4-5. Cumulative German Ammunition Tonnage Expended After Scaling Adjustment (STOCEM base case)

CHAPTER 5

ANALYSIS OF WEAPON SYSTEM LOSS RESULTS

5-1. INTRODUCTION. The purpose of this chapter is to portray and compare the simulation and historical weapon system loss results during the course of the Ardennes Campaign. The weapon systems represented are categorized into four classes: tanks, APCs, AT/Ms, and artillery. STOCEM and historical total system losses in each weapon class are depicted, at 4-day intervals for each force. Both cumulative losses and losses within each 4-day period are charted. Comparison of STOCEM with history is used to develop observations impacting on simulation validation and recommendations for CEM logic modifications to improve STOCEM model realism.

5-2. TANK LOSS RESULTS AND OBSERVATIONS

a. US/UK Tank Losses. Figure 5-1 shows base case STOCEM and historical cumulative (since STOCEM D-day of December 1944) total US/UK tanks lost. Values are plotted at 4-day intervals. Figure 5-2 shows base case STOCEM and historical total US/UK tanks lost during each 4-day period. Tank losses are defined as destroyed or abandoned tanks. Vehicles are abandoned when damaged and repairable but not recoverable because of adverse FEBA movement. The format of the charts is exactly analogous to that of Figure 4-1, i.e., each chart shows, for STOCEM, the mean value, the max/min band, and the 99 percent/90 percent confidence limit band.

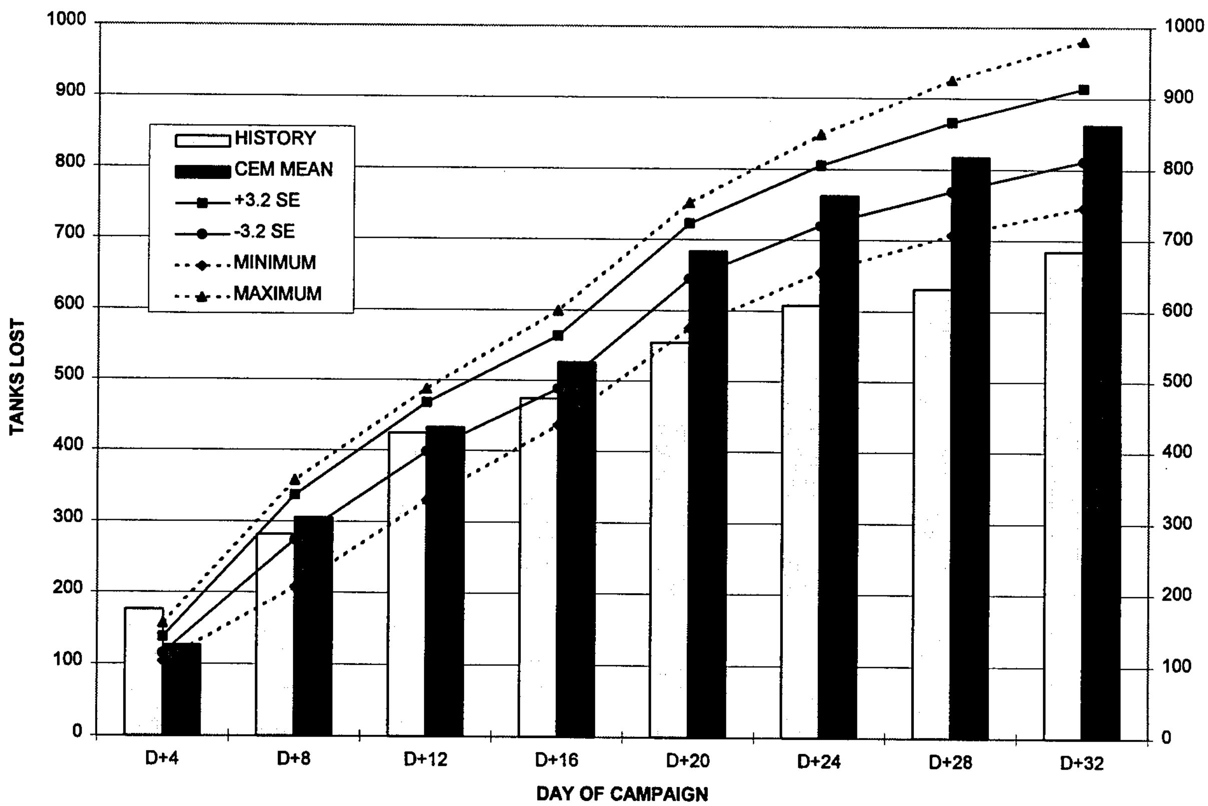


Figure 5-1. Cumulative US/UK Tank Losses (STOCEM base case)

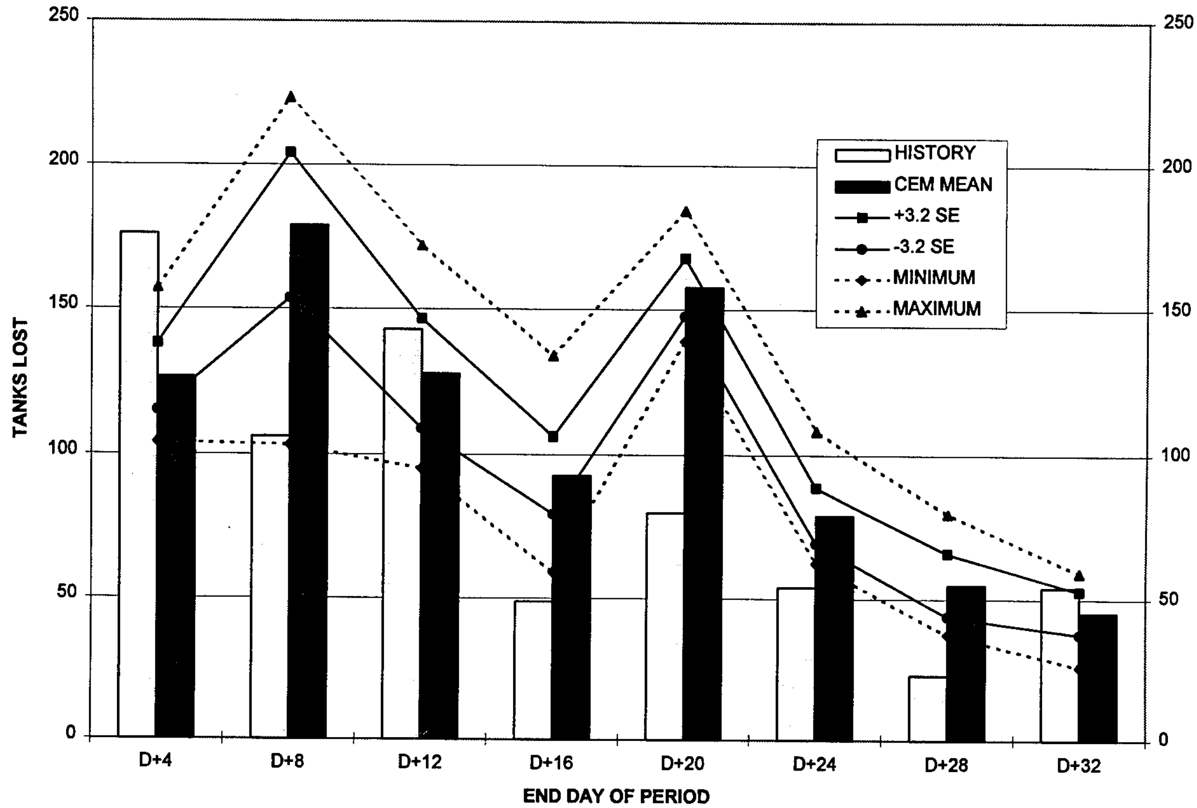


Figure 5-2. US/UK Tank Losses in Each 4-day Period (STOCEM base case)

Observations from the figures include:

(1) The widths of the STOCEM uncertainty bands, expressed as a fraction of the STOCEM mean value, tend to be larger for cumulative tank kills than for cumulative ammunition expenditures and for tank losses each 4-day period than for cumulative losses.

(2) The differences between historical and STOCEM results, expressed as a fraction of the historical result, also tend to be greater for cumulative STOCEM tank losses than for cumulative ammunition expenditures.

(3) During the first half of the campaign, STOCEM cumulative results, except for D+4, are very similar to cumulative history results, and historical losses are contained within the uncertainty bands. The difference, in figure 5-1, between cumulative historical kills and the nearest range limit (maximum or minimum) of STOCEM cumulative kill results is 21 tank kills or less through D+20. This difference is largest at D+28, when the STOCEM minimum is 77 kills in excess of the historical 631 kills.

(4) Historical losses are proportionately higher than STOCEM losses in the first 4 days of the campaign, while they are noticeably less than STOCEM's in the latter half of the

campaign. The historical cumulative tank losses "level off" as the campaign progresses from its midpoint. STOCEM does not exhibit such a marked "leveling off." It is possible that STOCEM was more aggressive in its employment of tanks and engaged them more closely and more frequently than history. The historical US/UK force may well have been more conservative in allowing risks to its weapon systems after sustaining an assault as surprisingly devastating as the first part of the Ardennes offensive.

(5) The 4-day period with the largest discrepancy between history and STOCEM is the period ending at D+20. From Figure 3-2, this coincides with the period when the largest fraction of the US/UK force was attacking. STOCEM tank attrition while attacking may be excessive.

b. German Tank Losses. Figure 5-3 shows base case STOCEM and historical cumulative (since D-day) total German tanks lost. Values are plotted at 4-day intervals. Figure 5-4 shows base case STOCEM and historical (since D-day) total German tanks lost during each 4-day period. Tank losses are defined as destroyed or abandoned tanks

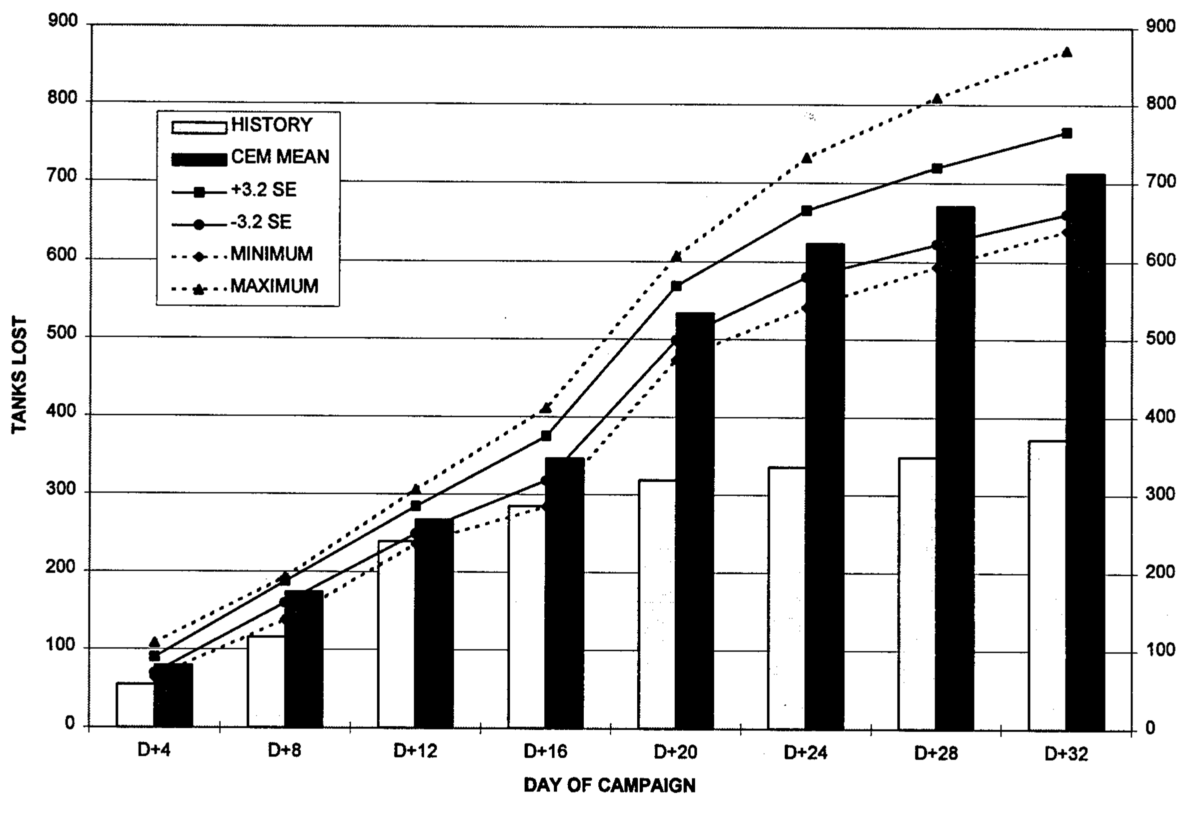


Figure 5-3. Cumulative German Tank Losses (STOCEM base case)

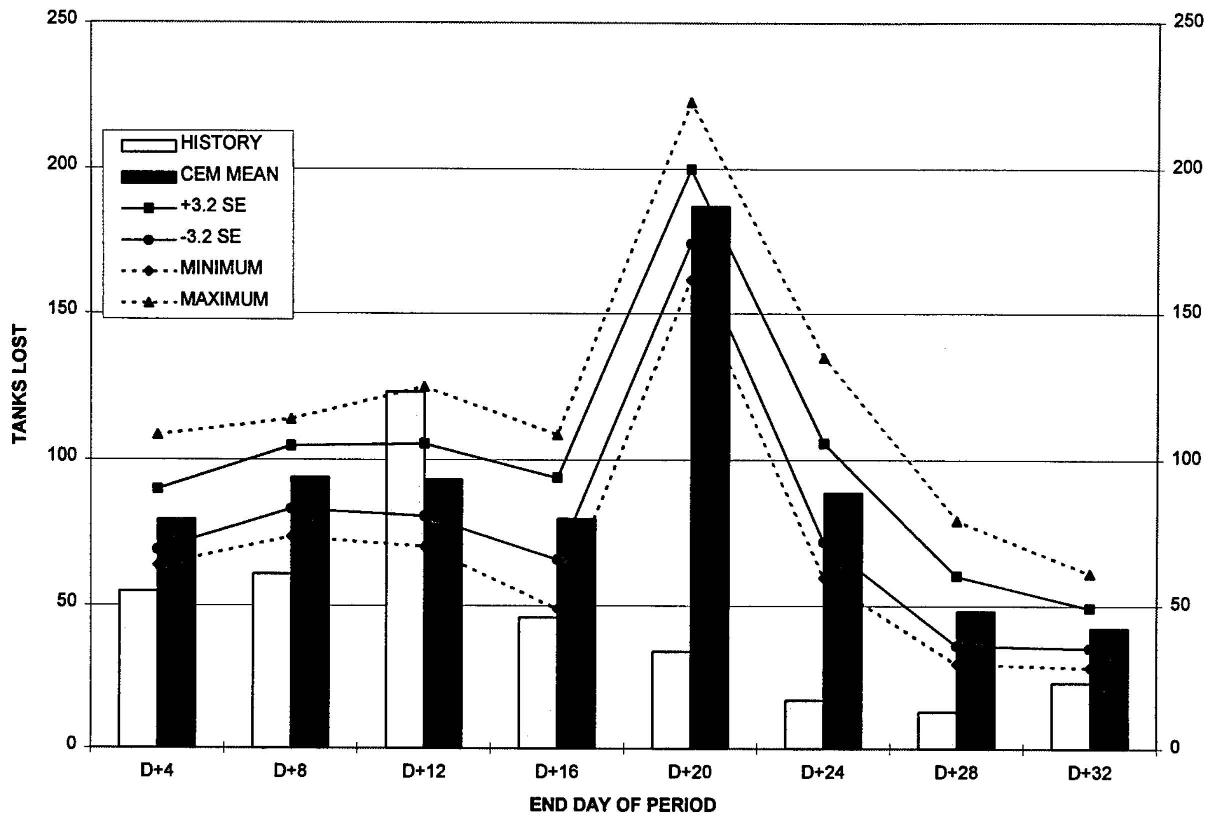


Figure 5-4. German Tank Losses in Each 4-day Period (STOCEM base case)

Observations from the charts include:

(1) The widths of the STOCEM uncertainty bands, expressed as a fraction of the STOCEM mean value, tend to be comparable and similar to those for US/UK tank kills.

(2) During the first half of the campaign, STOCEM cumulative loss results are again similar to history results, although historical losses are contained within the uncertainty bands only at D+12 and D+16. Thereafter, differences greatly increase.

(3) The 4-day periods with the largest discrepancy between history and STOCEM are the periods comprising D+16 through D+24. From Figure 3-2, these coincide with the only periods when a substantial part of the US/UK force was attacking. Total STOCEM German tanks killed during these two periods comprise 81 percent of all of the STOCEM German tanks killed during the last half of the campaign. These indicate that STOCEM tank attrition while attacking may be excessive. If German tank kills during the US/UK attack phase in D+16 through D+24 were substantially reduced, cumulative German tank kill results would be much closer to history. Modification of STOCEM logic and/or inputs to achieve this may be appropriate.

5-3. APC LOSS RESULTS AND OBSERVATIONS

a. US/UK APC Losses. Figure 5-5 shows base case STOCEM and historical cumulative (since D-day) total US/UK APCs lost. Values are plotted at 4-day intervals. Figure 5-6 shows base case STOCEM and historical (since STOCEM D-day) total US/UK APCs lost during each 4-day period. APC losses are defined as destroyed or abandoned APCs.

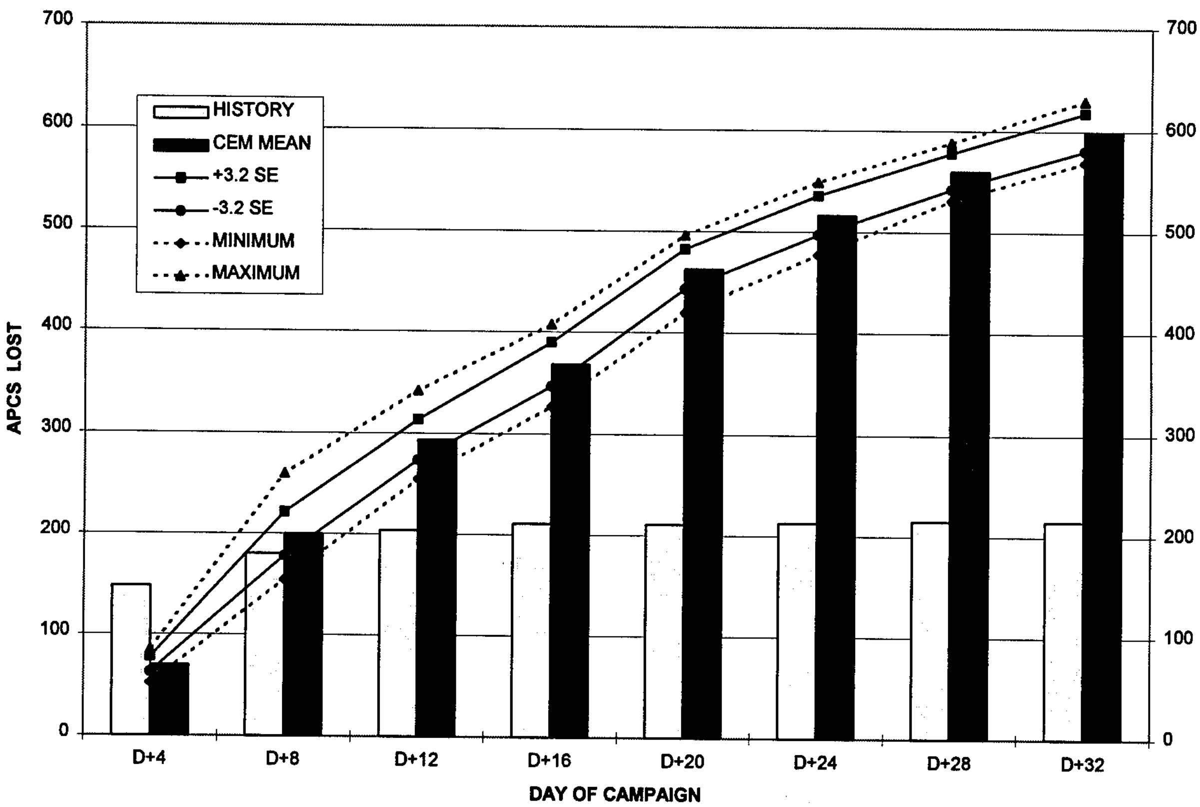


Figure 5-5. Cumulative US/UK APC Losses (STOCEM base case)

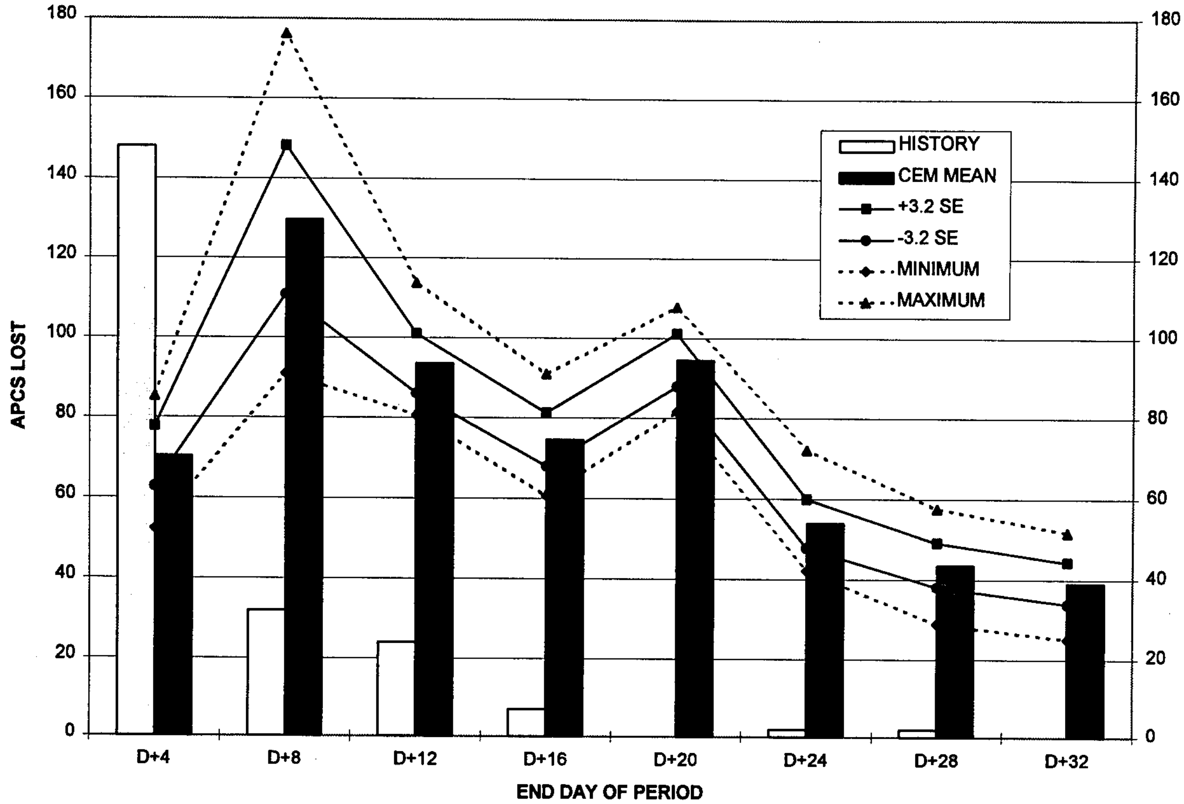


Figure 5-6. US/UK APC Losses in Each 4-day Period (STOCEM base case)

Observations from the figures include:

(1) The widths of the STOCEM uncertainty bands, expressed as a fraction of the STOCEM mean value, tend to be comparable and similar to those for US/UK tank kills.

(2) Except for the first 4-day period, the variation, over time, in STOCEM losses in each 4-day period strongly resembles the pattern for US/UK STOCEM tank losses in Figure 5-2.

(3) STOCEM kills many more APCs than occurred in history, especially after D+4. Kills after D+12 account for 51 percent of the STOCEM total, but only 5 percent of the historical total. Only 2 percent of historical losses occur after D+16. The most plausible explanation for the very low historical loss figure is a cautionary usage policy which kept the APCs from being sufficiently exposed to enemy weapon systems after a unit's initial engagement with a German unit. This was feasible since the tanks were likely the most forward weapon systems and, since the US/UK were on the offensive after D+16, their mechanized weapon systems (including APCs) behind the tanks were unlikely to be overrun by a defending enemy. In terms of a simulation model process, such a conservative usage policy is represented by a decreasing system vulnerability (based on decreasing exposure) over elapsing time. STOCEM, being based on averages and steady-state processes, is not designed to model such a policy. In any event, application of a "conservative system use" policy cannot be a model invariant, but must be scenario-dependent. Therefore, even if STOCEM could simulate conservative system use, it is up to the model user to decide when such a policy must be applied.

b. German APC Losses. Figure 5-7 shows base case STOCEM and historical cumulative (since D-day) total German APCs lost. Values are plotted at 4-day intervals. Figure 5-8 shows base case STOCEM and historical (since D-day) total German APCs lost during each 4-day period. APC losses are defined as destroyed or abandoned APCs.

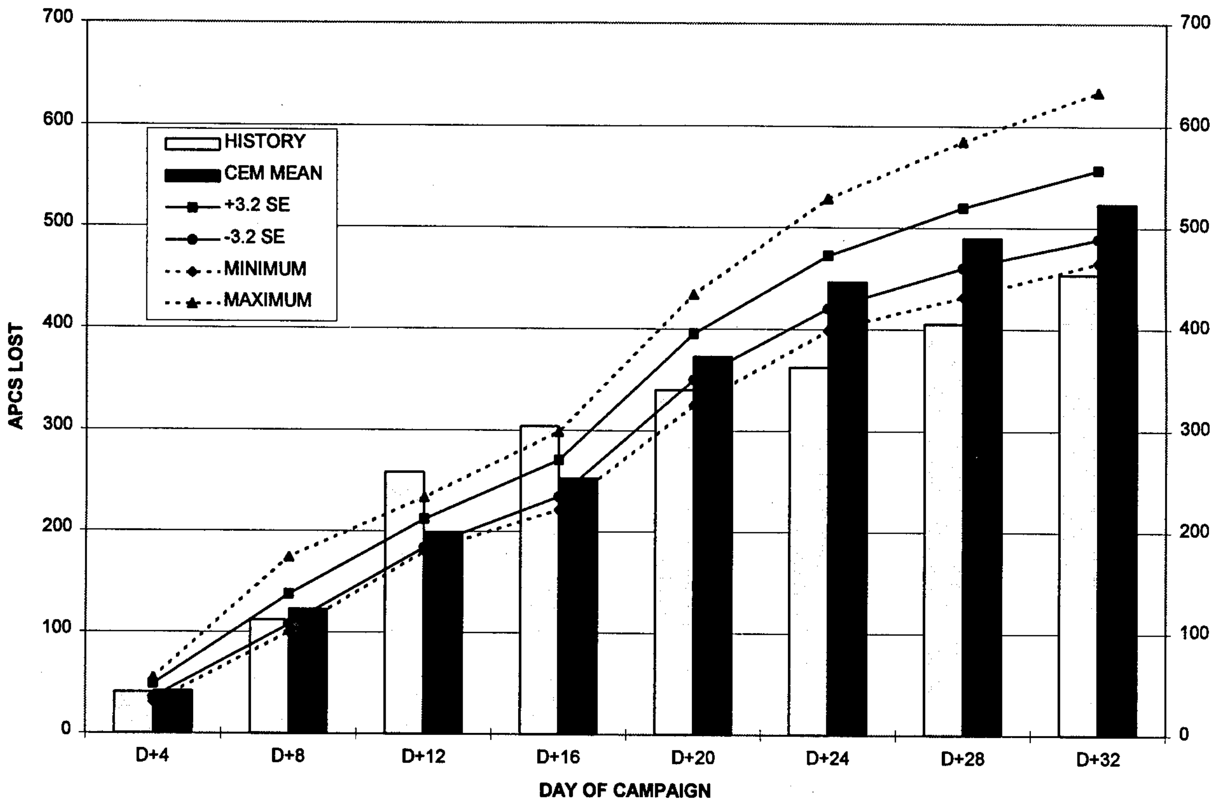


Figure 5-7. Cumulative German APC Losses (STOCEM base case)

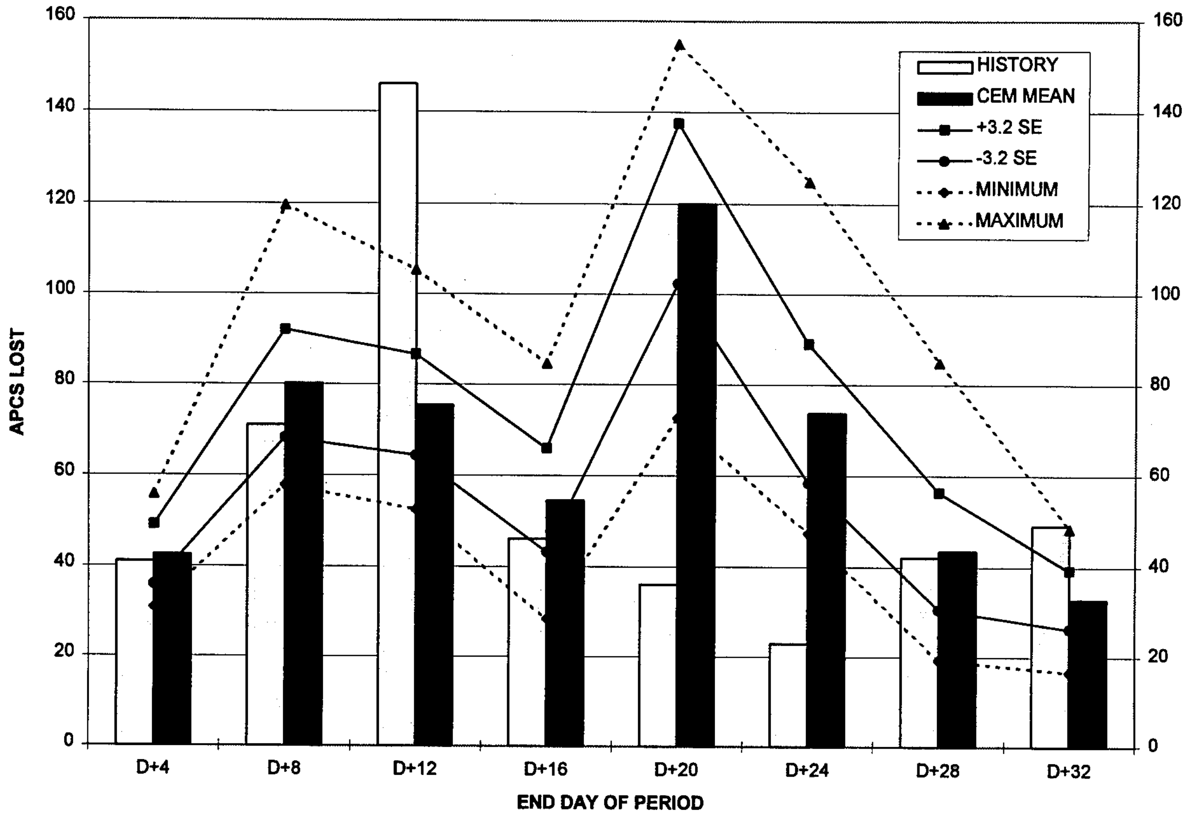


Figure 5-8. German APC Losses in Each 4-day Period (STOCEM base case)

Observations from the figures include:

(1) The widths of the STOCEM uncertainty bands, expressed as a fraction of the STOCEM mean value, tend to be comparable and similar to those for German tank kills, although APC losses in each 4-day period tend to show greater uncertainty than the comparable tank results.

(2) The variation, over time, in STOCEM losses in each 4-day period, is very similar to the pattern for STOCEM German tank losses shown in Figure 5-4.

(3) Although the historical cumulative APC kill results are within the STOCEM uncertainty bands at only three points in Figure 5-7 (D+4, D+8, and D+20), there is a similarity in trend with a divergence of 17 percent (STOCEM shortfall relative to history) at D+16, expanding only to a difference of 21 percent (STOCEM excess relative to history) at D+32.

(4) The 4-day periods with the largest discrepancy between history and STOCEM are the periods comprising D+16 through D+24. From Figure 3-2, these coincide with the only periods when a substantial part of the US/UK force was attacking. Total STOCEM German APCs killed during these two periods comprise 82 percent of all of the STOCEM German tanks killed during the last half of the campaign. These statistics are very similar to those for German tank kills and may well indicate that both tank and APC STOCEM attrition under attack posture may be excessive. If German APC kills during the US/UK attack phase in D+16 through D+24 were substantially reduced, cumulative German APC kill results would be much closer to history. Modification of STOCEM logic and/or inputs to achieve this may be appropriate.

5-4. AT/M LOSS RESULTS AND OBSERVATIONS

a. US/UK AT/M Losses. Figure 5-9 shows base case STOCEM and historical cumulative (since D-day) total US/UK antitank/mortar systems lost. Values are plotted at 4-day intervals. AT/M losses are defined as destroyed or abandoned AT/M systems. Figure 5-10 shows base case STOCEM and historical (since STOCEM D-day) total US/UK AT/Ms lost during each 4-day period.

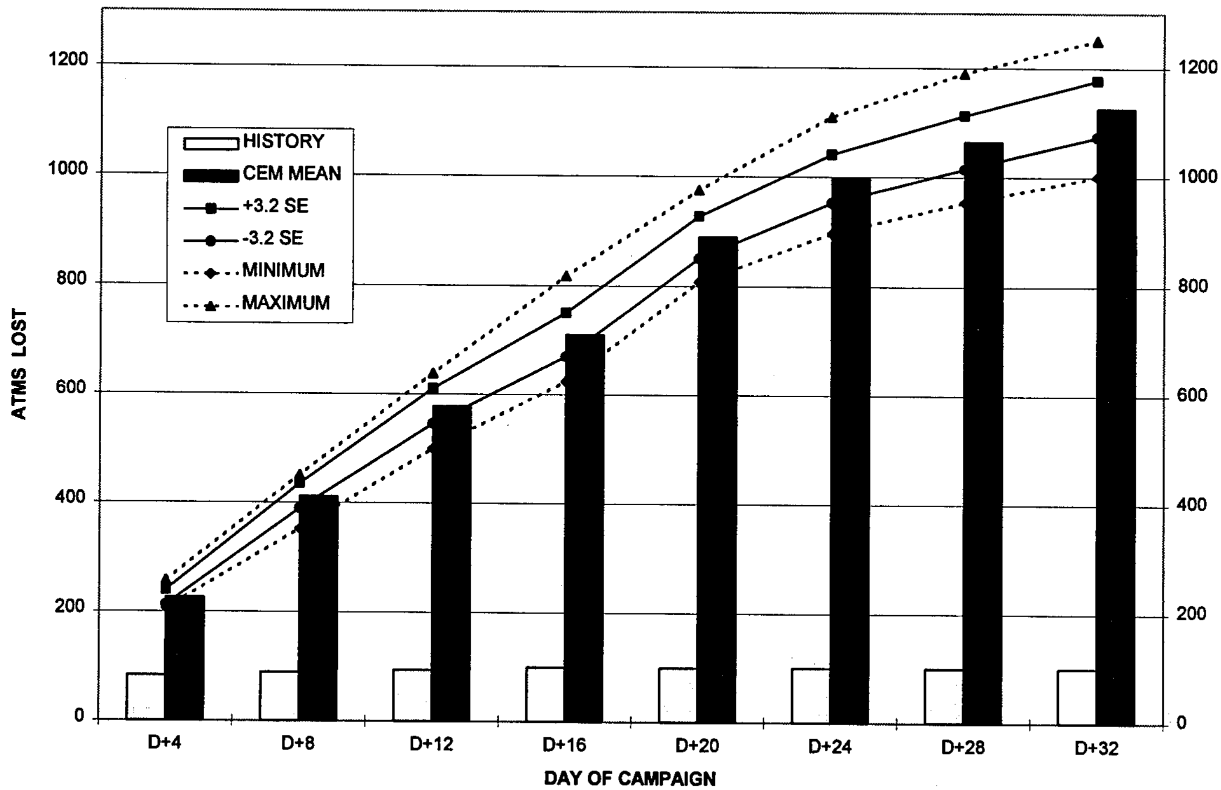


Figure 5-9. Cumulative US/UK AT/M Losses (STOCEM base case)

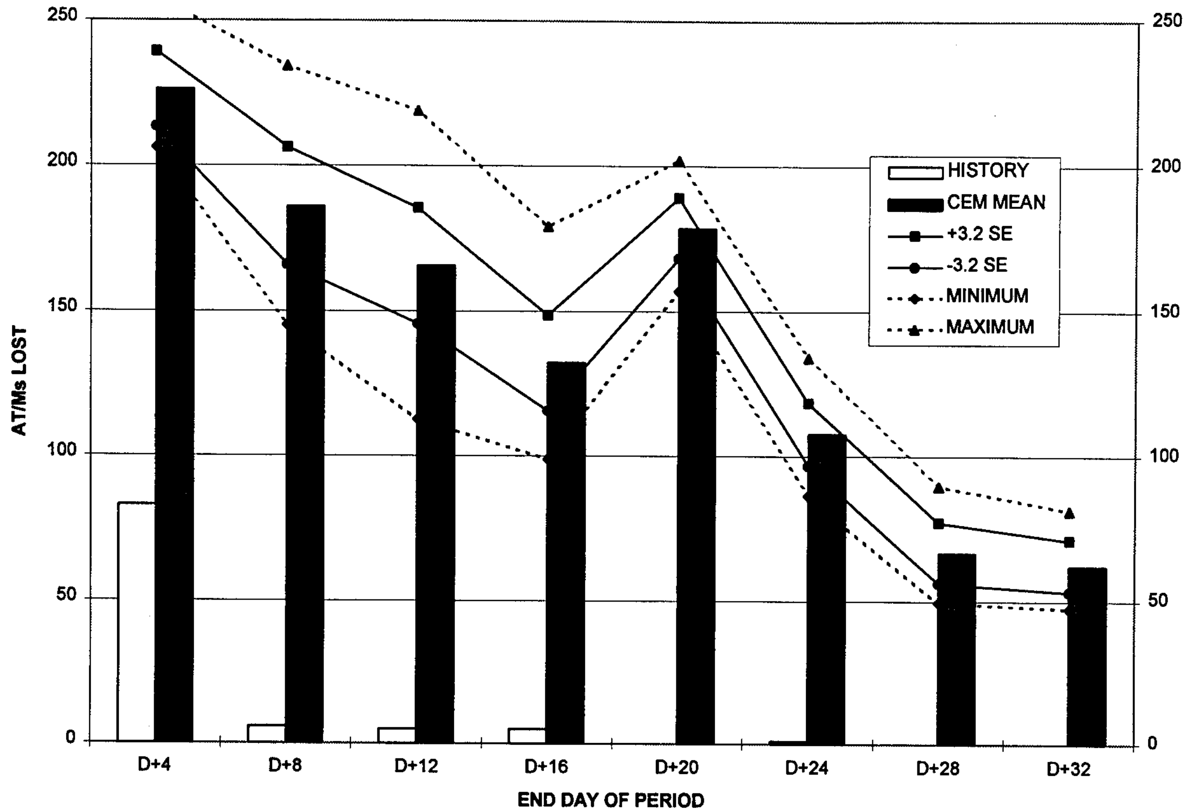


Figure 5-10. US/UK AT/M Losses in Each 4-day Period (STOCEM base case)

Observations from the figures include:

(1) The widths of the STOCEM uncertainty bands, expressed as a fraction of the STOCEM mean value, tend to be comparable and similar to those for US/UK tank kills.

(2) Except for the first 4 days of the campaign, the pattern of variation, over time, in STOCEM AT/M losses in each 4-day period is very similar to the patterns for both STOCEM US/UK tank losses and STOCEM US/UK APC losses, as shown in Figures 5-2 and 5-6.

(3) Both the magnitude and the time-phasing of STOCEM AT/M losses are very discrepant from history. Over the entire campaign, STOCEM kills over 11 times more AT/Ms than were killed historically. Also, kills after D+4 account for 80 percent of the STOCEM total, but only 17 percent of the historical total. Only 1 percent of historical losses occur after D+16. The large difference in number of systems lost (between STOCEM and history) indicates that vulnerability and exposure of these systems was probably significantly overestimated in the weapon system lethality/vulnerability input data for COSAGE, which generates the killer-victim tables used by STOCEM to calculate attrition. Examination and revision of the AT/M system data is suggested. As in the case of US/UK APC losses, the most plausible explanation for the high concentration of historical losses in the first 4 days is a cautionary usage policy which kept the AT/Ms from being exposed to enemy weapon systems after the main German offensive was blunted.

b. German AT/M Losses. Figure 5-11 shows base case STOCEM and historical cumulative (since STOCEM D-day) total German antitank/mortar systems lost. Values are plotted at 4-day intervals. AT/M losses are defined as destroyed or abandoned AT/M systems. Figure 5-12 shows base case STOCEM and historical (since STOCEM D-day) total German AT/Ms lost during each 4-day period.

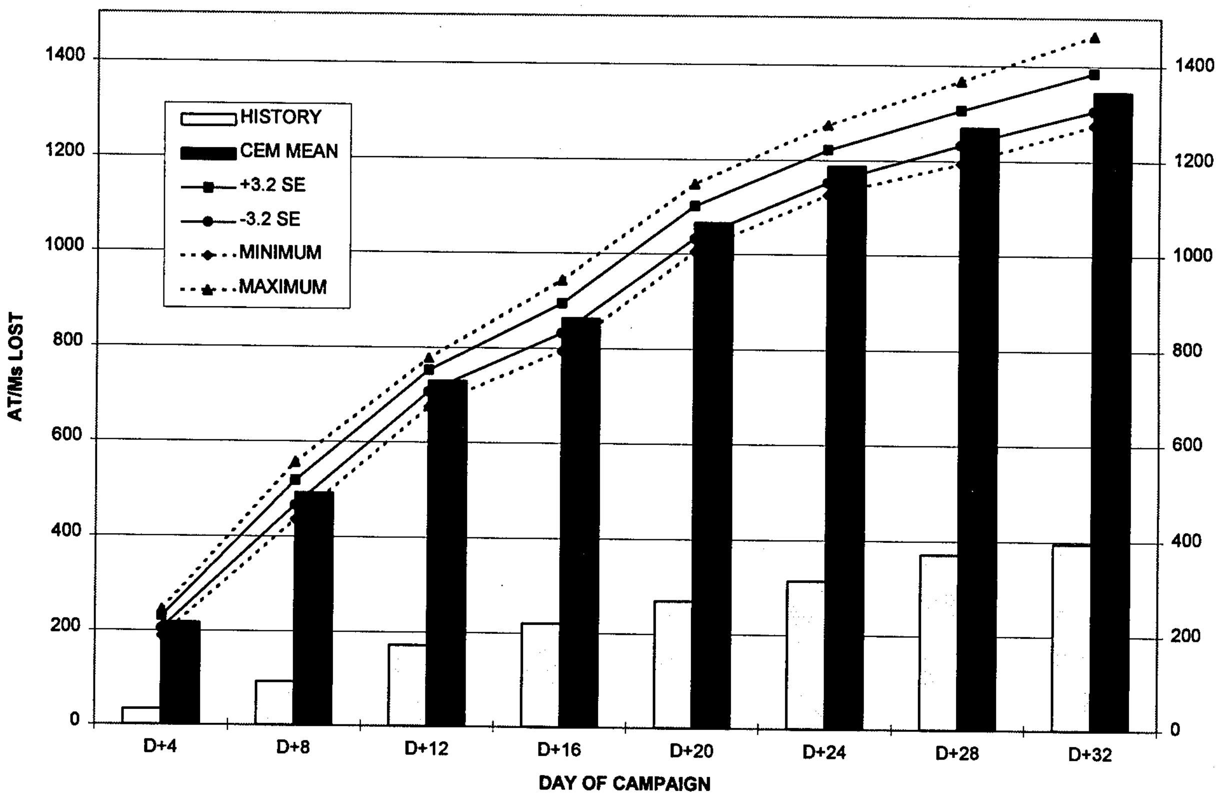


Figure 5-11. Cumulative German AT/M Losses (STOCEM base case)

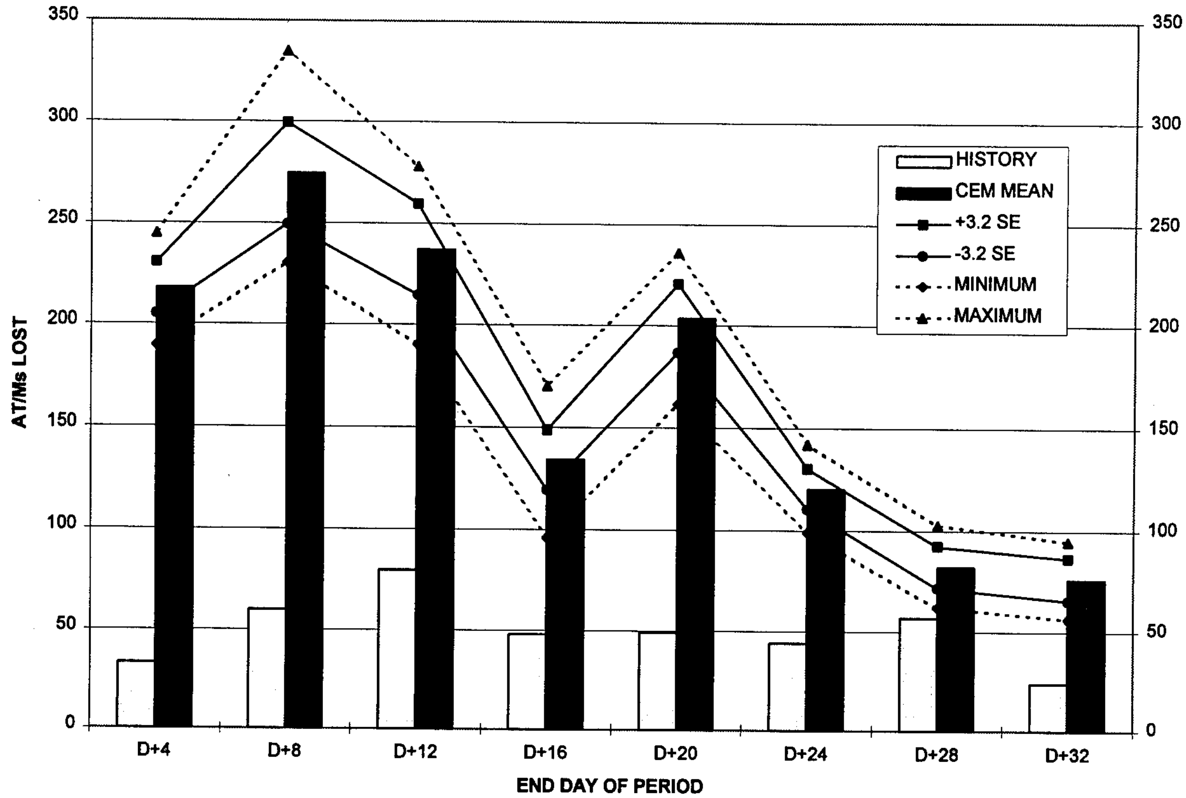


Figure 5-12. German AT/M Losses in Each 4-day Period (STOCEM base case)

Observations from the figures include:

(1) The widths of the STOCEM uncertainty bands, expressed as a fraction of the STOCEM mean value, tend to be somewhat narrower than those for German APC kills.

(2) Except for the first 4-day period, the pattern of variation, over time, in STOCEM German AT/M losses in each 4-day period is similar to the pattern for STOCEM German APC losses.

(3) Both the magnitude and the time-phasing of STOCEM AT/M losses are very discrepant from history. Over the entire campaign, STOCEM kills 240 percent more German AT/Ms than were killed historically. Except for a small peak in the period ending at D+12, historical German AT/M losses in each 4-day period are relatively stable until a marked decline in losses in the last 4 days. The large differences in number of systems lost (between STOCEM and history) indicate that vulnerability and/or exposure of these systems was probably significantly overestimated in the weapon system lethality/vulnerability input data for COSAGE, which generates the killer-victim tables used by STOCEM to calculate attrition. Examination and revision of the AT/M system lethality/vulnerability input data to COSAGE are suggested.

5-5. ARTILLERY LOSS RESULTS AND OBSERVATIONS

a. US/UK Artillery Losses. Figure 5-13 shows base case STOCEM and historical cumulative (since D-day) total US/UK artillery tubes lost. Values are plotted at 4-day intervals. Artillery losses are defined as destroyed or abandoned artillery tubes. Figure 5-14 shows base case STOCEM and historical (since D-day) total US/UK artillery tubes lost during each 4-day period.

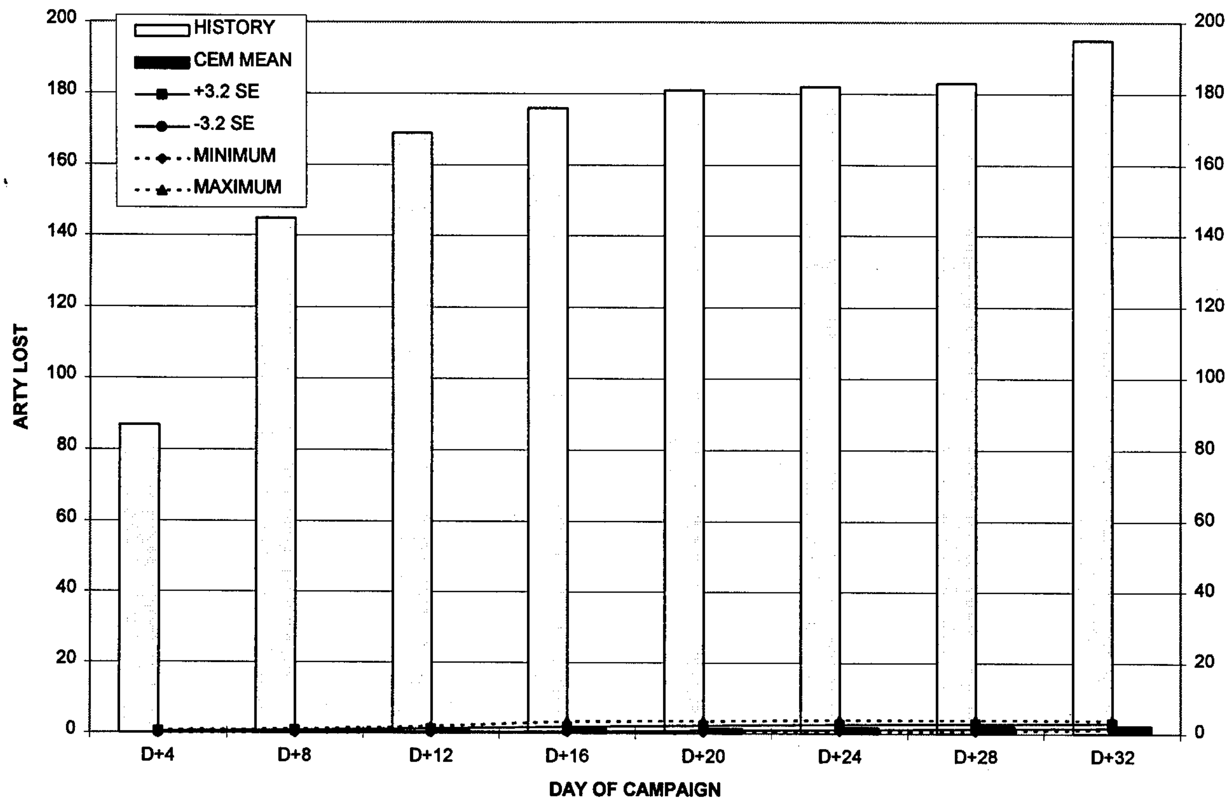


Figure 5-13. Cumulative US/UK Artillery Losses (STOCEM base case)

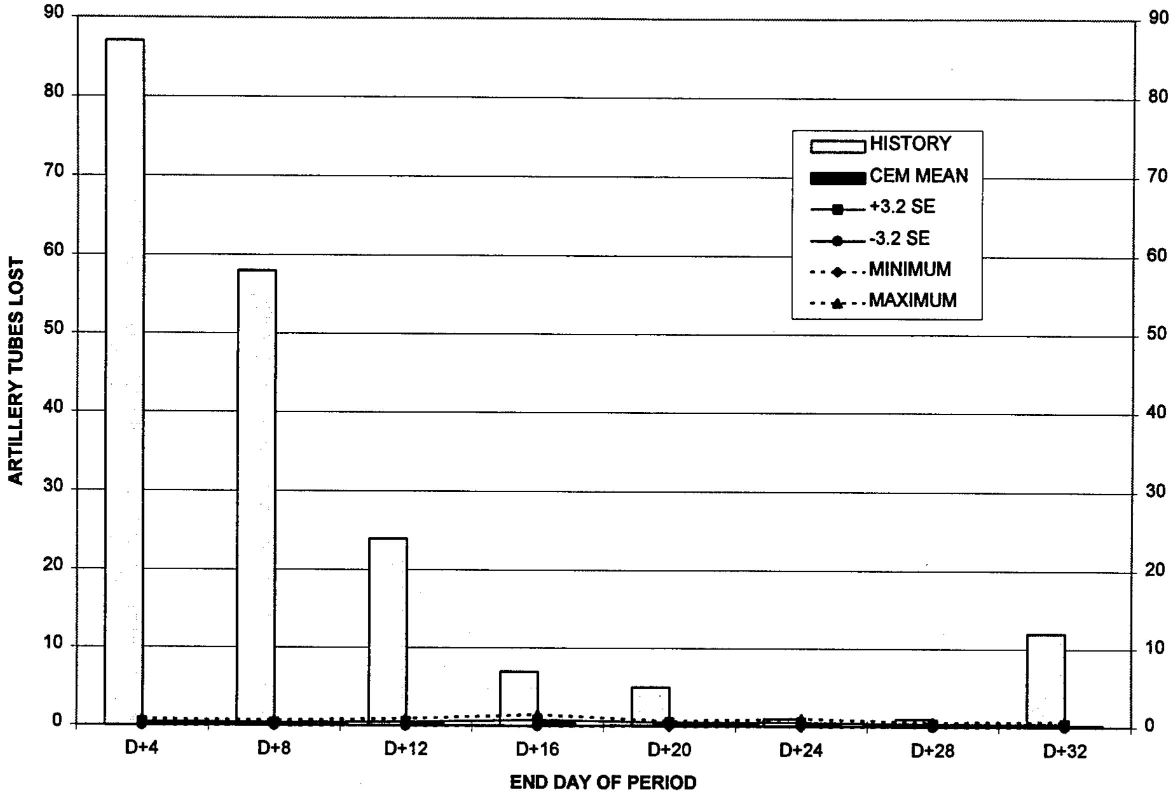


Figure 5-14. US/UK Artillery Losses in Each 4-day Period (STOCEM base case)

(1) STOCEM produces negligible US/UK artillery losses, while history shows 195 tubes destroyed or abandoned during the entire campaign. The vast majority of historical artillery losses (86 percent) occurred before D+12. By and large, these losses were due to the US/UK forces being overrun and/or surprised during the initial phase of the German offensive. Artillery were especially vulnerable to loss in such a situation. Danny S. Parker (Ref. 11) writes:

> "Artillery was simply too vulnerable to remain on the front - it had to be evacuated if the enemy broke through the lines. Engineers could be used when absolutely necessary and both sides in the Ardennes reluctantly committed these forces in such a fashion. However, their lack of combat support elements made them unable to hold a position long if confronted by a conventional enemy combat force."

The ingredients of surprise and fortuitous circumstances facilitating the catastrophic breakthrough of the initial German advance are not modeled in STOCEM. Both history and STOCEM show negligible US/UK artillery losses if the effects of this catastrophic breakthrough are discounted. These results indicate a need for STOCEM to be modified so as to simulate breakthrough effects. Also, STOCEM does not represent the abandonment of repairable, damaged artillery due to a rapidly advancing enemy.

(2) Vulnerability and/or exposure of US/UK artillery may have been underestimated in the weapon system lethality/vulnerability input data for COSAGE, which generates the killer-victim tables used by STOCEM to calculate attrition. Examination and revision of the artillery system lethality/vulnerability input data to COSAGE are suggested.

b. German Artillery Losses. Figure 5-15 shows base case STOCEM and historical cumulative (since STOCEM D-day) total US/UK artillery tubes/launchers lost. Values are plotted at 4-day intervals. Artillery losses are defined as destroyed or abandoned artillery tubes/launchers. Figure 5-16 shows base case STOCEM and historical (since STOCEM D-day) total US/UK artillery tubes lost during each 4-day period.

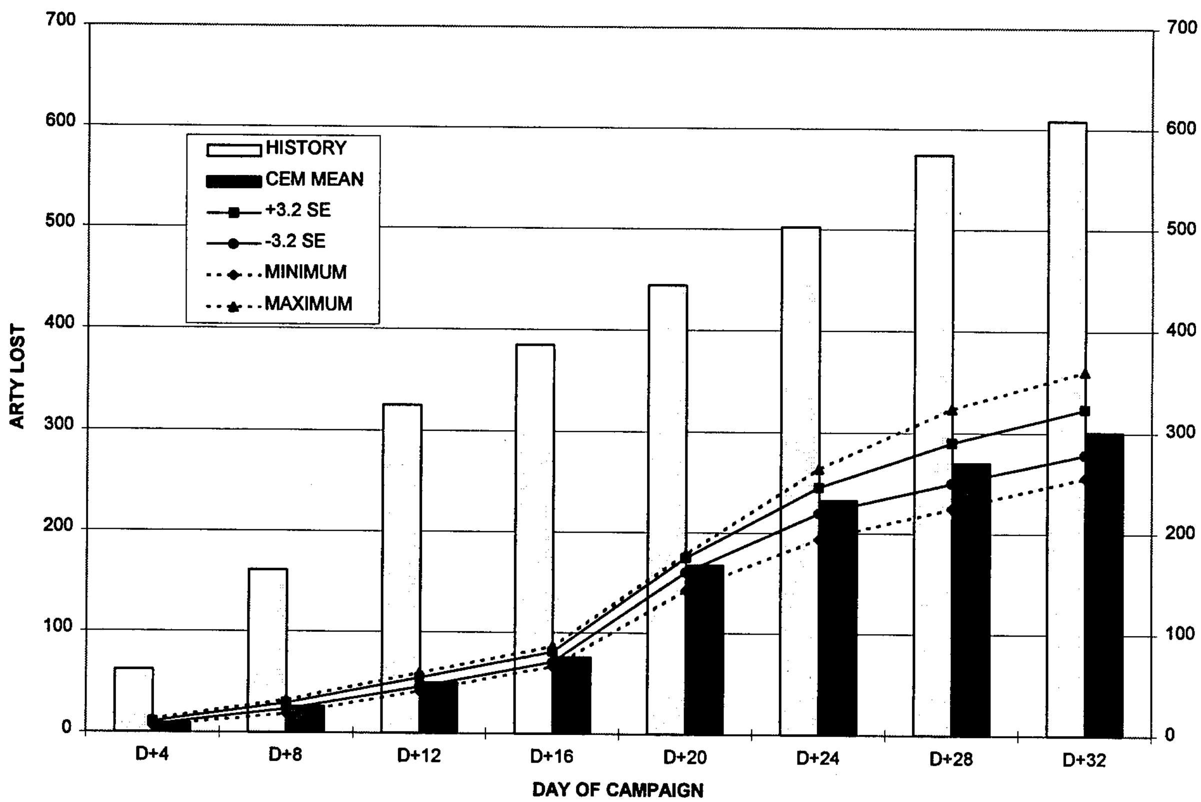


Figure 5-15. Cumulative German Artillery Losses (STOCEM base case)

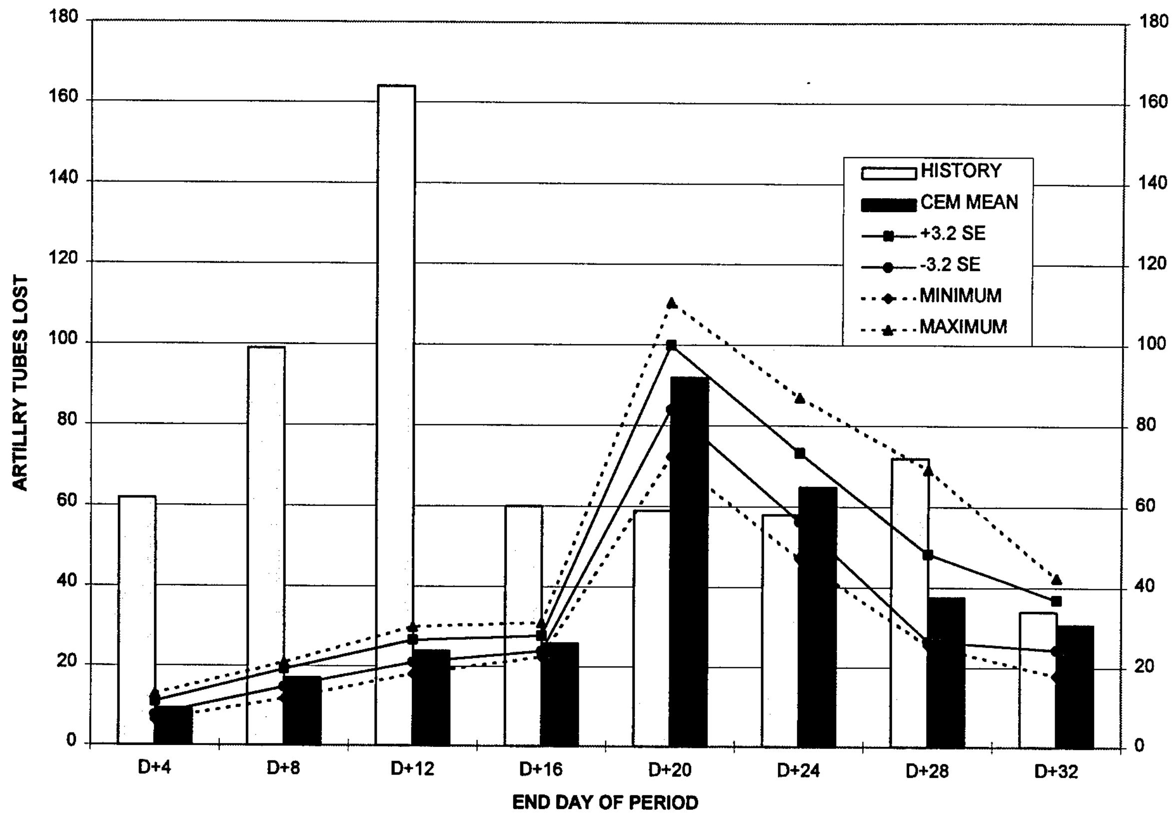


Figure 5-16. German Artillery Losses in Each 4-day Period (STOCEM base case)

Observations from the figures include:

(1) Over the whole campaign, STOCEM German artillery kills are almost half the number of historical kills.

(2) During the last half of the campaign, in which the US/UK were on the offensive, total STOCEM losses (=225) are almost identical to the total historical losses (=223). Figure 5-16 shows a reasonable similarity between STOCEM and historical artillery losses in each 4-day period after D+16.

(3) The major discrepancies (between STOCEM and history) occur during the German offensive phase of the first 12 days of the campaign, when STOCEM kills are only 15 to 17 percent of historical kills. The vulnerability/exposure of German artillery in the attack was apparently severely underestimated. A reevaluation of the associated weapon system lethality/vulnerability inputs to COSAGE is suggested.

5-6. OVERALL SYSTEM SUMMARY

a. US/UK Weapon System Losses. Figure 5-17 shows the ratio of base case STOCEM results to historical results for the cumulative STOCEM US/UK mean weapon system losses in Figures 5-1, 5-5, and 5-9. The fraction overestimation by STOCEM is reflected in the quantity: [1.00 - displayed ratio]. The artillery ratio is essentially zero throughout the figure. Figure 5-18 shows the fraction of all STOCEM US/UK mean losses which occur in each 4-day period of the campaign. (These fractions, for a system type, must sum to 1.00 over the entire campaign.) Figure 5-19 shows the fraction of all historical losses which occur in each 4-day period of the campaign.

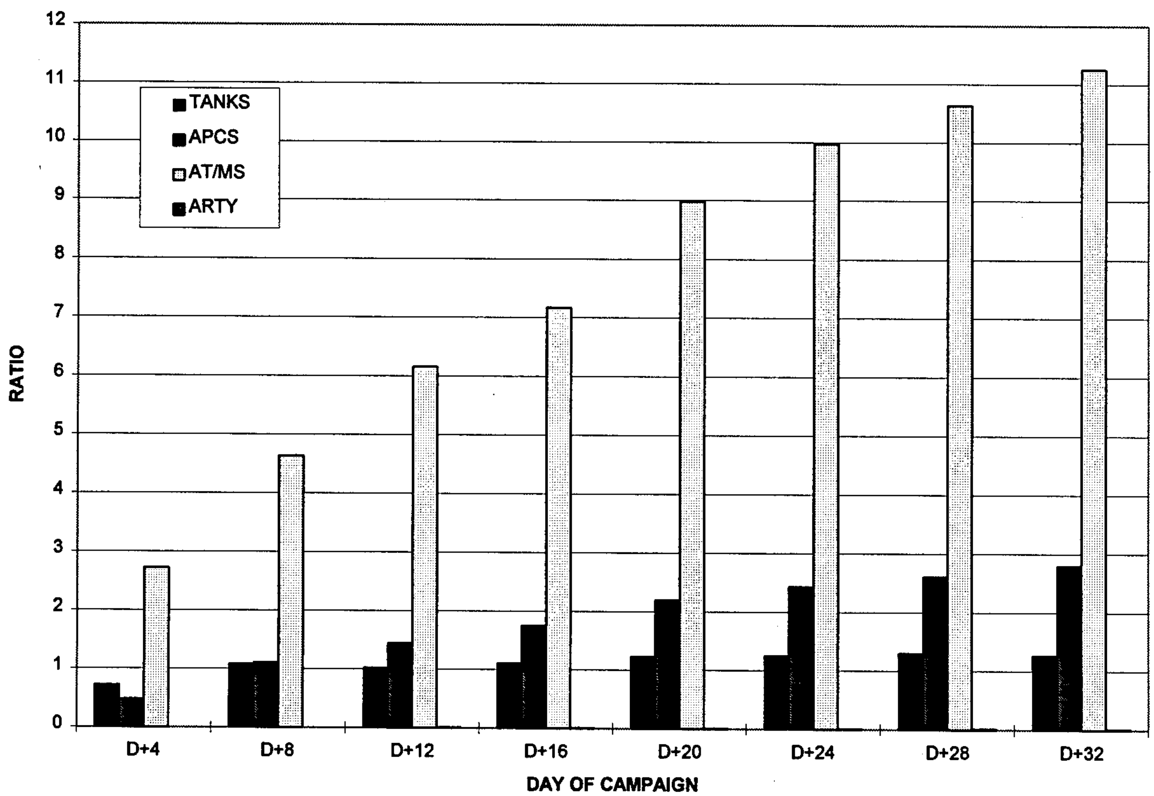


Figure 5-17. Ratio of Cumulative STOCEM US/UK Losses to Cumulative Historical Losses (STOCEM base case)

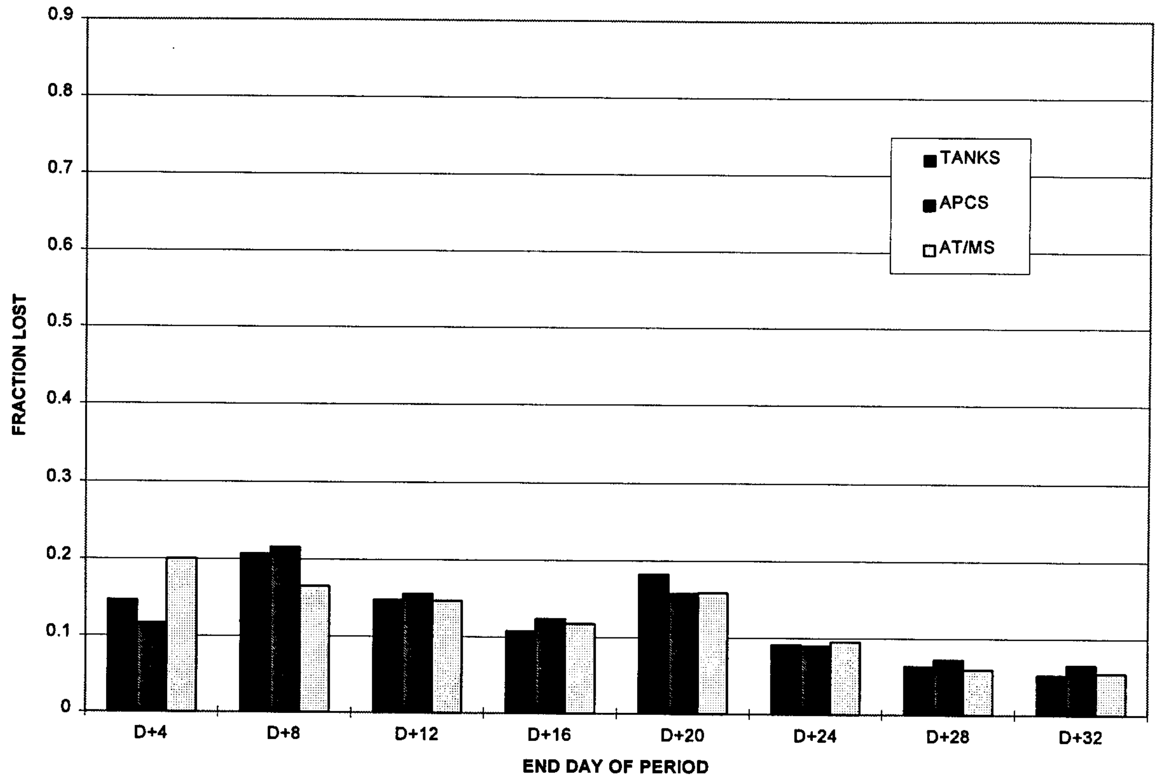


Figure 5-18. Fraction of Total STOCEM US/UK Losses in Each 4-day Period (STOCEM base case)

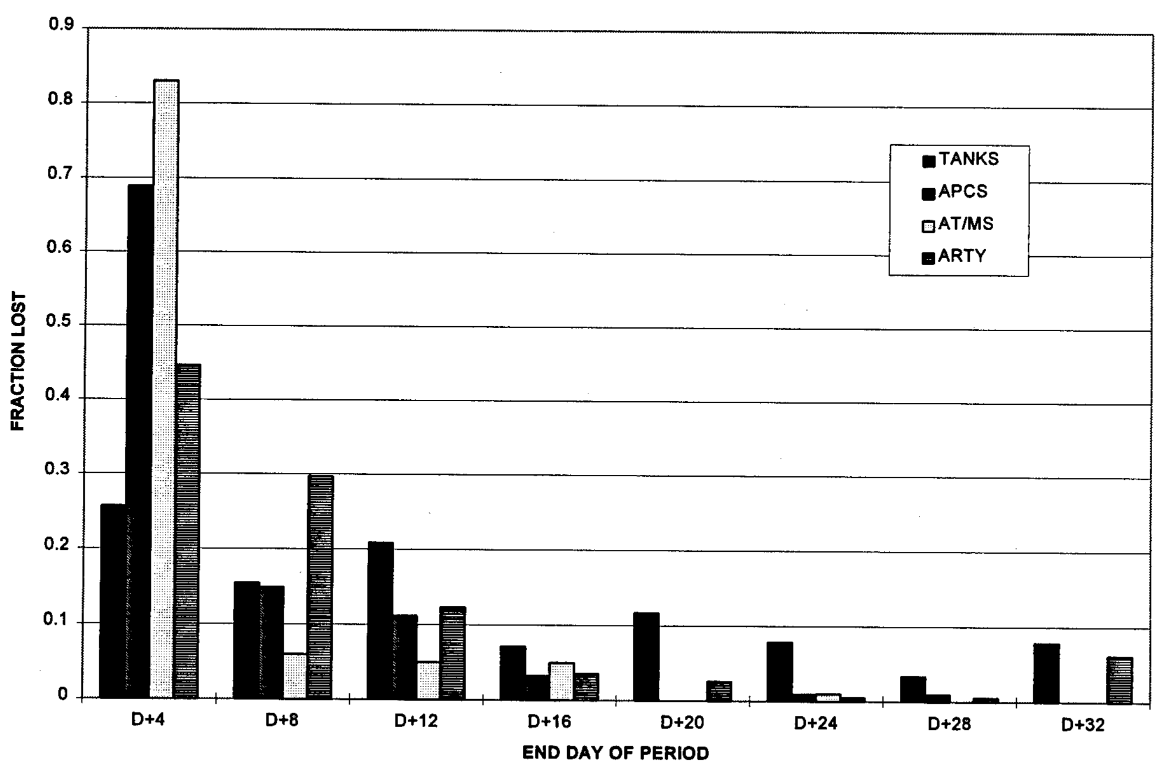


Figure 5-19. Fraction of Total Historical US/UK Losses in Each 4-day Period

These figures confirm and contrast the observations noted earlier:

(1) Except for artillery, STOCEM tended to kill more systems than history. Subjectively ranking cumulative kills of STOCEM US/UK system types according to agreement with history yields the order:

(a) Tanks: reasonably close agreement.

(b) APCs: STOCEM losses are 200 percent more than historical over the campaign.

(c) AT/Ms: STOCEM losses are 10 times more than historical over the campaign.

(d) Artillery: STOCEM losses are less than 1 percent of historical losses.

For tanks, APCs, and AT/Ms, the fraction of "overkill," relative to history, generally increased as the campaign progressed. Examination of Figures 5-18 and 5-19 shows that, except for tanks, the distribution of STOCEM kills over the campaign differed markedly from history. Proportions of STOCEM kills in each 4-day period vary only gradually between 22 percent early in the campaign to 6 percent near the end of the campaign. Corresponding proportions of historical kills, except for tanks, are heavily concentrated in the first 4 days of the campaign, with the last half of the campaign accounting for only a tiny fraction of total kills. Historical tank kills were more nearly evenly distributed throughout the campaign. A plausible inference is that the Allies' reduced vulnerability of their mechanized weapon systems (the APCs, AT/Ms, and artillery) after the German offensive "punch" was blunted in the first 8 days of the campaign. Such a reduction in vulnerability may reflect a cautionary use policy which restricted these systems' exposure to enemy weapon systems and forces when the US/UK strength was enough to prevent being overrun. Tanks apparently acted as lead weapon systems which always had to operate near the FEBA under relatively constant exposure to enemy weapons.

(2) Both history and STOCEM show negligible US/UK artillery losses if the effects of catastrophic breakthrough, not modeled in STOCEM, are discounted. The remaining excess of STOCEM over historical losses may reflect some underestimation of lethality/vulnerability inputs used in the COSAGE processor program.

(3) As was noted in paragraphs 5-2 and 5-3, there are indications that STOCEM kills an excessive number of German tanks and APCs (relative to history) when a substantial part of the US/UK force is in attack posture. The difficulty of calculating German STOCEM posture information from the scenario precludes a comparable analysis from US/UK system losses.

b. German Weapon System Losses. Figure 5-20 shows the ratio of base case STOCEM results to historical results for the cumulative STOCEM mean German weapon system losses in Figures 5-3, 5-7, 5-11, and 5-15. Figure 5-21 shows the fraction of all STOCEM mean German losses which occur in each 4-day period of the campaign. Figure 5-22 shows the fraction of all historical German losses which occur in each 4-day period of the campaign.

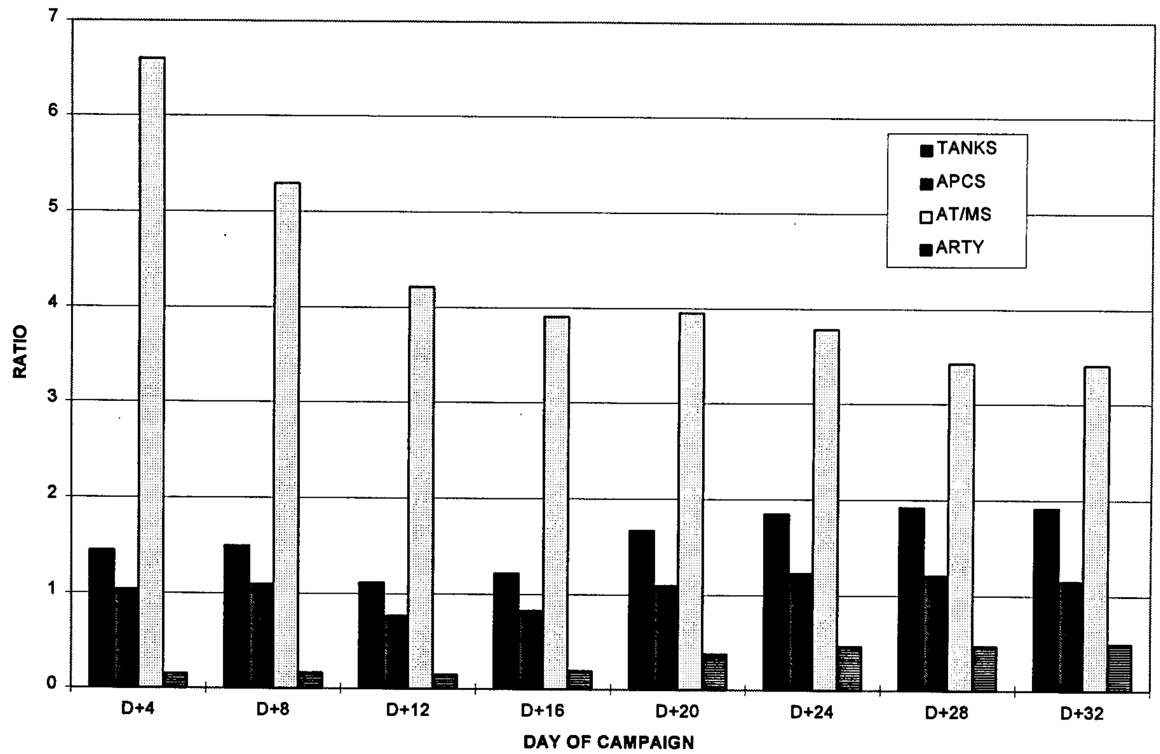


Figure 5-20. Ratio of Cumulative STOCEM German Losses to Cumulative Historical Losses (STOCEM base case)

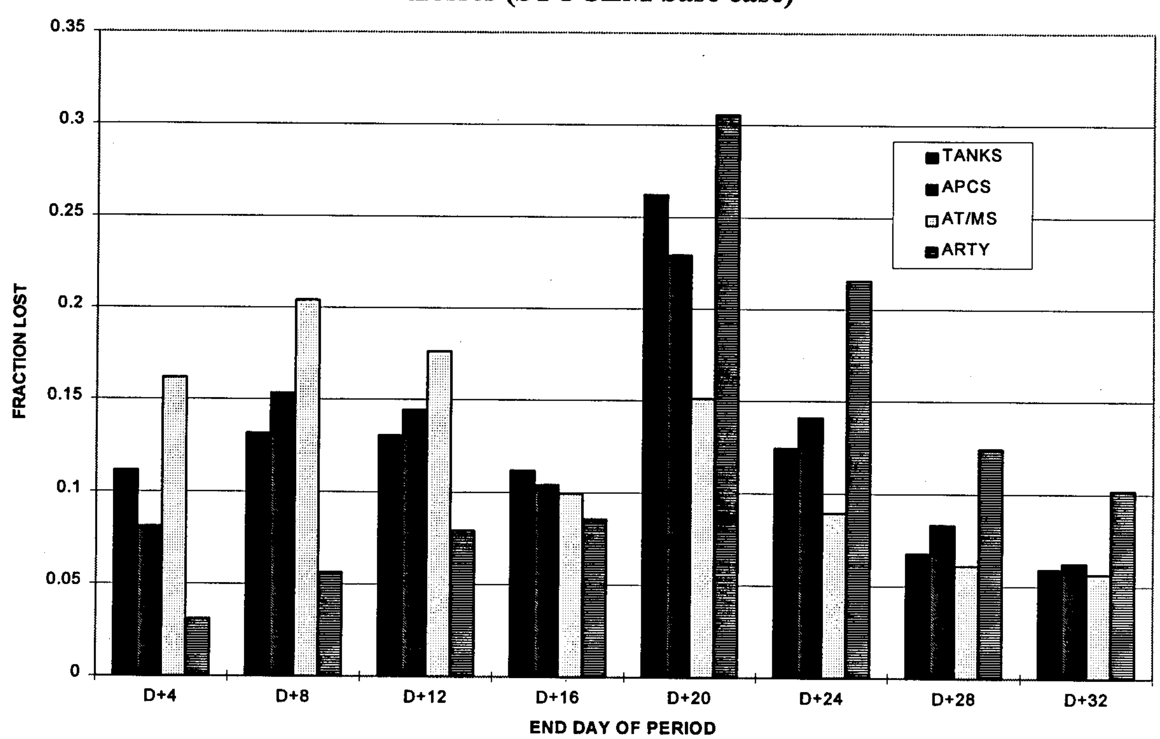


Figure 5-21. Fraction of Total STOCEM German Losses Generated in Each 4-day Period (STOCEM base case)

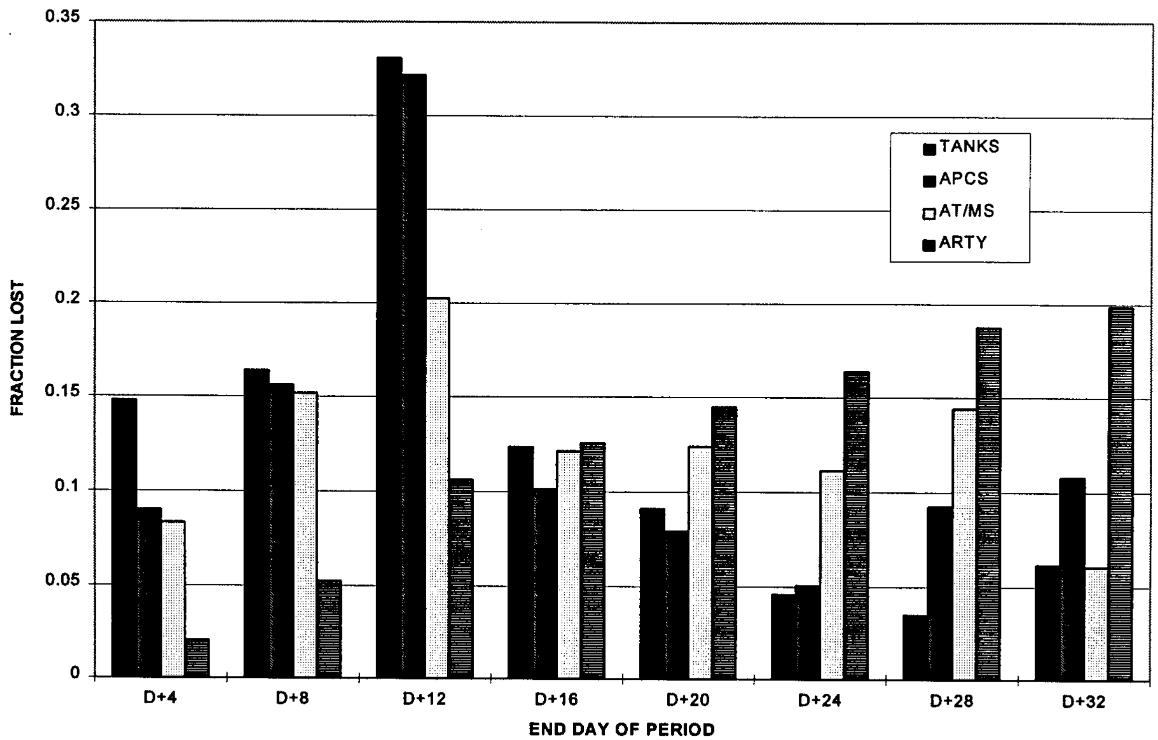


Figure 5-22. Fraction of Total Historical German Losses Generated in Each 4-day Period

These figures confirm and contrast the observations noted earlier:

(1) Except for artillery, STOCEM tended to kill more systems than did history. Subjectively ranking cumulative kills of STOCEM German system types according to agreement with history yields the order:

(a) APCs: fairly close agreement.

(b) Tanks: although there is reasonably close agreement with history during the first half of the campaign, STOCEM kills almost twice as many as history over the campaign.

(c) Artillery: STOCEM losses are less than a third of historical.

(d) AT/Ms: STOCEM losses are generally three to six times historical losses.

(2) Comparison of Figures 5-21 and 5-22 shows that, unlike the US/UK, the historical German losses are not disproportionately concentrated in the early days, but are generally relatively evenly distributed throughout the campaign. An exception is the 4-day period ending in D+12, in which the fraction lost (of total losses) is approximately double that of other periods. Historically, this period is the turning point of the German offensive. The loss distribution indicates that the German force did not practice a policy of successfully reducing exposure of its mechanized weapon systems during the campaign. The increased exposure (and losses) may reflect a greater tendency for the German force to take risks.

(3) STOCEM losses are also generally relatively evenly distributed throughout the campaign. An exception is the 4-day period ending in D+20, in which the fraction lost (of total losses) is approximately double that of other periods. This corresponds to the period when the largest fraction of the US/UK force was attacking (see Figure 3-2).

(4) Figures 5-19 and 5-22 indicate that historical losses on both sides were heaviest in the first 12 days of the campaign, when the Germans were attacking. The most disproportionate STOCEM losses shown in Figure 5-21 occur in German losses for the 4-day period ending on D+20 when most of the STOCEM US/UK force was attacking and when 23-30 percent of STOCEM German tank, APC, and artillery losses occurred. These results support the inference, previously deduced, that STOCEM may kill too many systems in the attack posture, especially when the US/UK force is attacking.

5-7. EXCURSION CASE RESULTS. Appendix G contains a complete set of weapon system loss results for the STOCEM excursion case scenario, as well as comparative results for the STOCEM base case vs the STOCEM excursion case. There is an exact analogue of each STOCEM base case chart displayed in this chapter. Summary observations on overall comparison of STOCEM base case and STOCEM excursion case results include:

a. Over the entire campaign, the STOCEM excursion case usually resulted in slightly more system losses than the base case. However, the increase (over the base case) in STOCEM excursion case losses was substantially higher in the first 4 days of the campaign. The increase in losses also tended to be larger for tanks and APCs than for AT/Ms and artillery. Since the STOCEM base case, except for artillery, usually killed more than history, the STOCEM excursion case usually deviated more from history than did the STOCEM base case.

b. The distribution of system kills over 4-day periods in the campaign was similar to the distributions in the STOCEM base case, except for substantial increases over the STOCEM base case in the first 4 days of the campaign excursion. Except for the first 4 days, the pattern of variation in system losses over 4-day periods in the campaign in the STOCEM excursion case was very similar to the pattern for the STOCEM base case.

5-8. SUGGESTED STOCEM MODIFICATIONS. STOCEM modifications suggested by ARCAS analyses are described below. These modifications may require changes in STOCEM logic and/or in inputs to the simulation (including inputs to the COSAGE processor). Each topic heading is parenthetically qualified with the areas (model logic and/or inputs) judged to be affected by the suggested changes.

a. Reduction of Lethality in Attack Posture (logic). The STOCEM US/UK system loss results , in conjunction with the STOCEM US/UK engagement posture profiles, yielded indications that STOCEM may kill an excessive number of German tanks and APCs when a substantial part of the US/UK force is in attack posture. Based on ARCAS results, it would appear that, in the "real world," an attacking force may well kill more conservatively, over time, than is reflected in the current STOCEM algorithms. A reduction of an attacking force's lethality against enemy tanks and APCs appears appropriate, with a higher reduction associated with a higher strength advantage (for the attacker). The CAA CEM maintenance staff should assess whether and, if appropriate, how, the ATCAL attrition logic of CEM could be modified to incorporate this lethality reduction process.

b. Simulation of a Conservative Use of Mechanized Weapons (logic and inputs). The US/UK losses for mechanized weapon systems (APCs and AT/Ms) indicates that vulnerability and exposure of these systems was probably significantly overestimated in the weapon system lethality/vulnerability input data for COSAGE, which generates the killer-victim tables used by STOCEM to calculate attrition. Examination and revision of the AT/M system data is suggested. In the case of US/UK APC and AT/M losses, the most plausible explanation for the high concentration of historical losses in the first 4 days is a cautionary usage policy which kept the AT/Ms from being exposed to enemy weapon systems after the main German offensive was blunted. Such a reduction in vulnerability may reflect a cautionary use policy which restricted these systems' exposure to enemy weapon systems and forces when the US/UK strength was enough to prevent being overrun. STOCEM should be able to simulate such a "conservative use" policy for a force's mechanized weapon systems. Current STOCEM decision logic does apply some conservation of resources. When STOCEM applies a "delay" posture instead of a "defend" posture, it does so, in part, to reduce losses at a cost of increased retrograde movement. The decreased losses in delay posture must be represented in COSAGE preprocessor inputs to STOCEM. In order to reflect the conservative system use policy reflected in the ACSDB, STOCEM logic should probably be modified to allow a reduction in the currently "standard" ATCAL vulnerability of mechanized weapon systems when a force:

(1) Is not being heavily attacked, but has sustained a period of heavy losses while defending against an attacking force for 4 to 8 days.

(2) Also has a sufficient strength advantage to prevent an enemy advance or counteroffensive.

The application of such a vulnerability reduction should:

(1) Not be applied to tank systems opposing an armored force. Tanks are therefore assumed to always be employed sufficiently forward so that application of a conservative usage/exposure policy is very limited in the face of an enemy with significant armor.

(2) Probably be an optional attribute since a force may (perhaps out of a "fanatical" attitude/posture) not exercise such significant conservation of combat resources even though circumstances are favorable to it.

(3) Probably be correlated with the suggested FEBA logic change described in Chapter 3, which moderates FEBA movement after a "sufficiently sustained advance."

(4) Be correlated with the attack posture lethality reduction modification noted in paragraph 5-8a, above. The ARCAS results support the hypothesis that an attacking force that is strong enough to significantly displace an opposing force is generally more conservative than

STOCEM in both the rate at which it "kills" enemy armor and in the rate that it allows its own weapon systems to "be killed."

The CAA CEM maintenance staff should examine whether and, if appropriate, how, the ATCAL attrition logic of CEM could be modified to incorporate a policy of conservation of mechanized weapon resources consistent with the above attributes.

c. Simulation of Catastrophic Breakthrough Attrition Effects (logic). The occurrence of the vast majority of historical US/UK APC, AT/M, and artillery losses in the initial 4 to 8 days of the campaign coincides with, and is an effect of, the "catastrophic breakthrough" nature of the initial German attacks. This breakthrough effect was produced by a combination of speed, surprise, and (initially) overwhelming force. During the historical campaign, this effect caused a rapid and dramatic rise in US/UK attrition rates, due in large part to the abandonment of weapons and the encirclement and capture of personnel. The current CEM (and STOCEM) does not model such a breakthrough effect. The large disproportions, over time, in ARCAS US/UK system losses indicate that CEM is currently biased in favor of a defender when modeling an attacker capable of (and executing) a catastrophic breakthrough. Methods should be investigated to modify the CEM attrition to include, insofar as possible, the accelerated tempo of breakthrough effects. CEM currently extrapolates and interpolates attrition rates implicit in tables of posture-dependent battle results, denoted as "combat samples," generated by COSAGE. The attrition rates implicit in these samples are applicable to sustained combat in each posture. In a sense, the breakthrough effect is a type of "high intensity attack" posture that is not represented in current COSAGE combat samples or in the CEM extrapolation from these samples. A "breakthrough" combat attack posture generating significantly accelerated defender attrition and depending on speed and overwhelming force advantage should be defined and treated both in the COSAGE combat samples and in CEM.

d. Increased Vulnerability of Artillery (inputs). The somewhat larger (than historical) STOCEM artillery losses suggest that increases in the input (to COSAGE) vulnerability of ARCAS artillery systems may be appropriate. Even though both STOCEM and historical losses in US/UK artillery are similarly negligible after catastrophic breakthrough effects are discounted, the historical losses still consistently exceed those generated by STOCEM.

CHAPTER 6

ANALYSIS OF PERSONNEL CASUALTIES

6-1. INTRODUCTION. The purpose of this chapter is to portray and compare the simulated and historical personnel casualty results during the course of the Ardennes Campaign. ARCAS STOCEM casualties and historical total casualties are compared for both sides and are charted at 4-day intervals in the scenario. Casualty results are partitioned into four category types for the US/UK force. Selected daily casualty rates and fraction of total casualties in each category type during the campaign are charted only for the US/UK force. Comparison of ARCAS STOCEM with history is used to develop observations impacting on simulation credibility and recommendations for CEM input and/or logic modifications to improve model realism. The history vs STOCEM comparisons are used to develop a rule for redistributing ARCAS STOCEM casualties over the four casualty types to bring simulated casualties closer to history. A complete set of US/UK personnel loss rate results, for both scenario cases, is in Appendix H.

6-2. TOTAL PERSONNEL CASUALTIES. Total casualties are the sum of the KIA and CMIA, WIA, and DNBI. In addition to the STOCEM average value, the figures show the STOCEM maximum and minimum over the 16 STOCEM replications, along with the 99 percent/90 percent confidence limits (denoted as +3.2 SE and -3.2 SE in the chart). These two pairs of lines form bands which graphically portray the uncertainty in stochastic variation in the STOCEM casualty results.

a. US/UK Personnel Casualties. Figure 6-1 shows base case STOCEM and historical cumulative (since STOCEM D-day) total US/UK personnel casualties at 4-day intervals. Figure 6-2 shows base case STOCEM and historical (since STOCEM D-day) total US/UK personnel casualties during each 4-day period. Analogous charts showing total casualties in each casualty type (KIA, WIA, CMIA, DNBI) are in Appendix H.

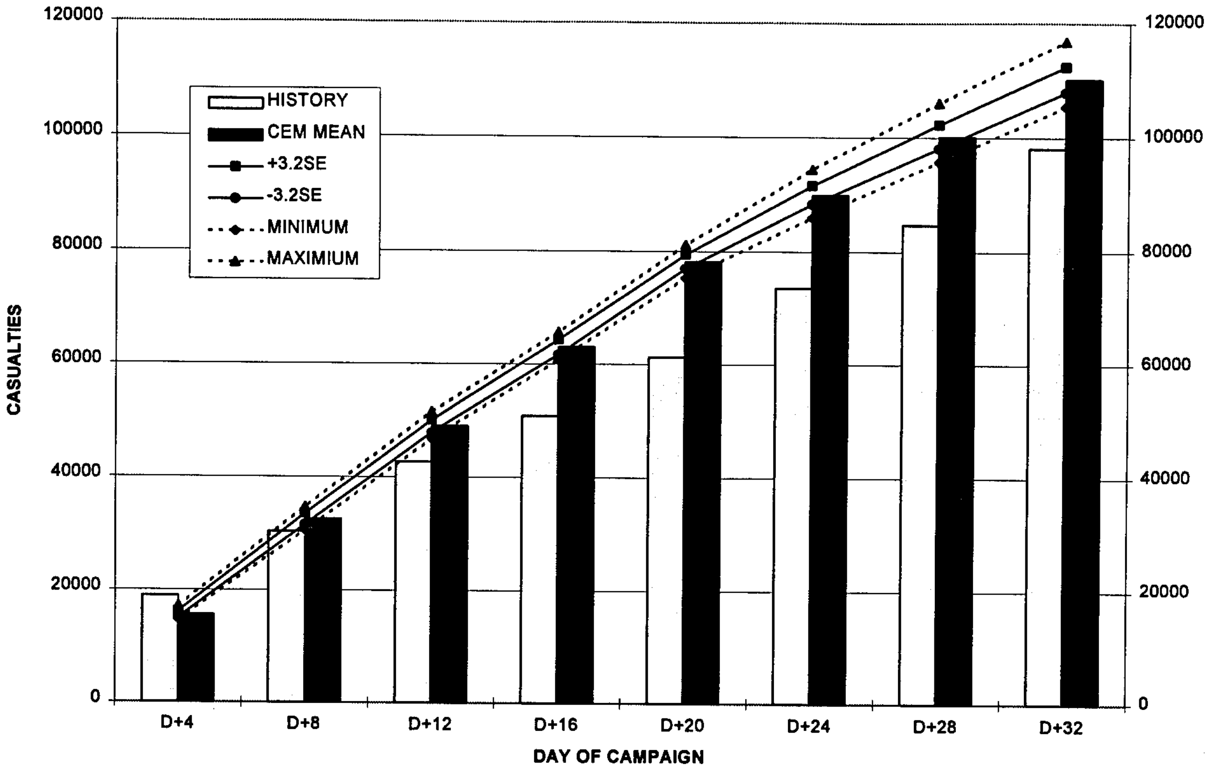


Figure 6-1. Cumulative US/UK Personnel Losses (STOCEM base case)

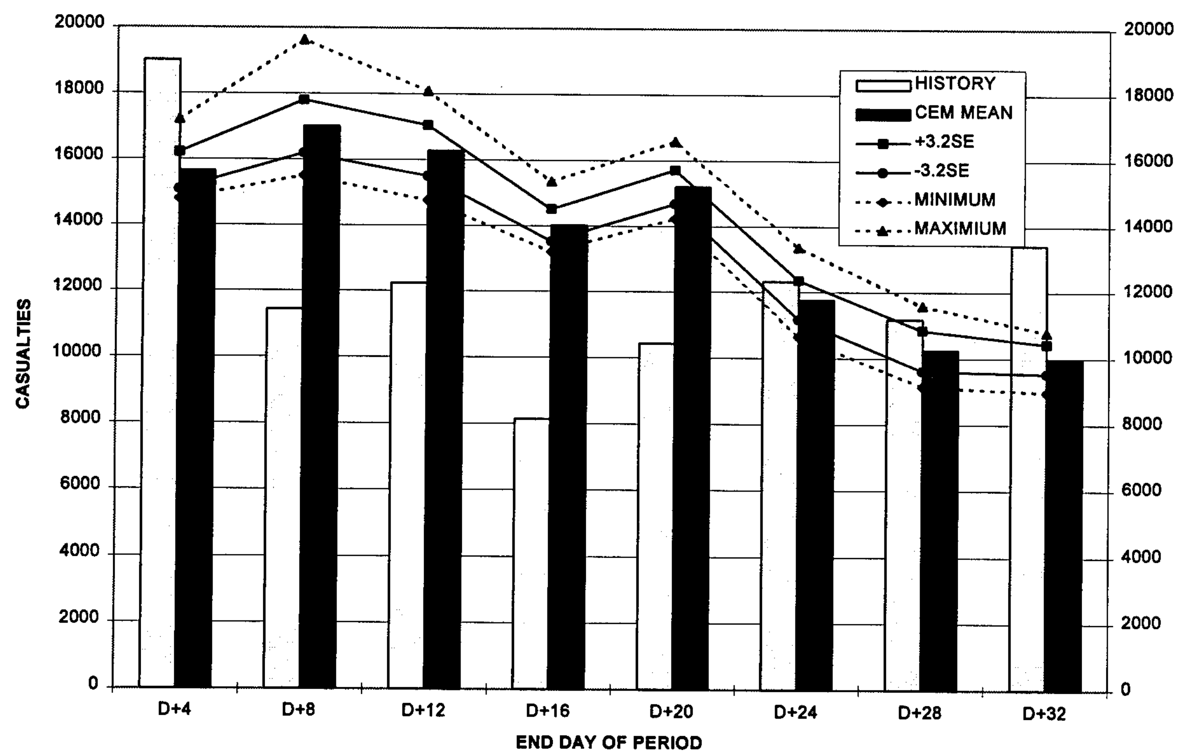


Figure 6-2. US/UK Personnel Losses in Each 4-day Period (STOCEM base case)

Observations derivable from the figures include:

(1) The narrowness of the STOCEM uncertainty bands indicates that variability in STOCEM casualty results is (proportionately) considerably less than the variability in STOCEM weapon system losses and FEBA results.

(2) Although the historical cumulative casualty results are rarely within the STOCEM uncertainty bands, they appear to be similar to the STOCEM averages both in magnitudes and trend (over time). STOCEM tends to produce more casualties than actually occurred. Overall cumulative STOCEM casualties during the entire campaign were about 12 percent larger than history.

(3) Figure 6-2 shows that the 4-day periods with the greatest STOCEM deviations from history were the periods ending at D+8, D+16, and D+20, when STOCEM generated too many casualties. Since the period ending at D+8 was near the peak of the German attack and since Allies in STOCEM had the largest representation in attack posture during the period ending at D+20, these results indicate that STOCEM personnel attrition in attack posture may be excessive and should be moderated.

b. German Personnel Casualties. Figure 6-3 shows base case STOCEM and historical cumulative (since STOCEM D-day) total German personnel casualties at 4-day intervals. Figure 6-4 shows base case STOCEM and historical (since STOCEM D-day) total German personnel casualties during each 4-day period.

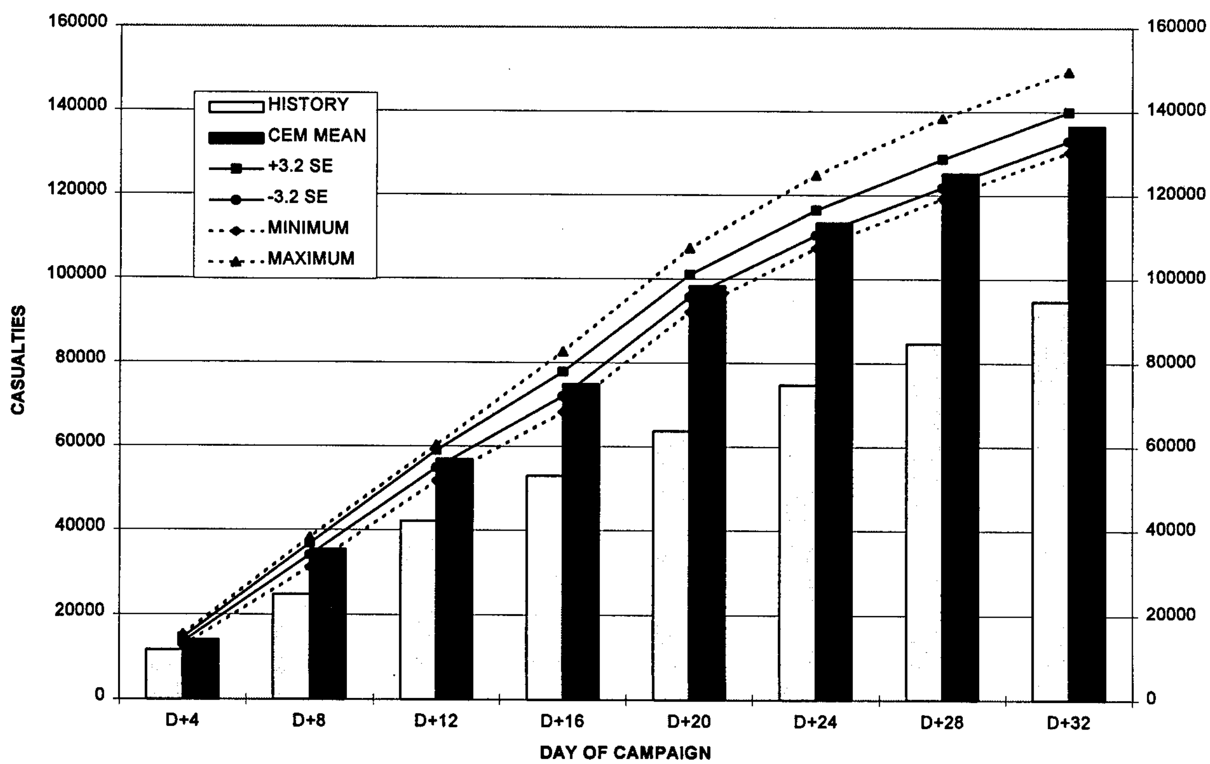


Figure 6-3. Cumulative German Personnel Losses (STOCEM base case)

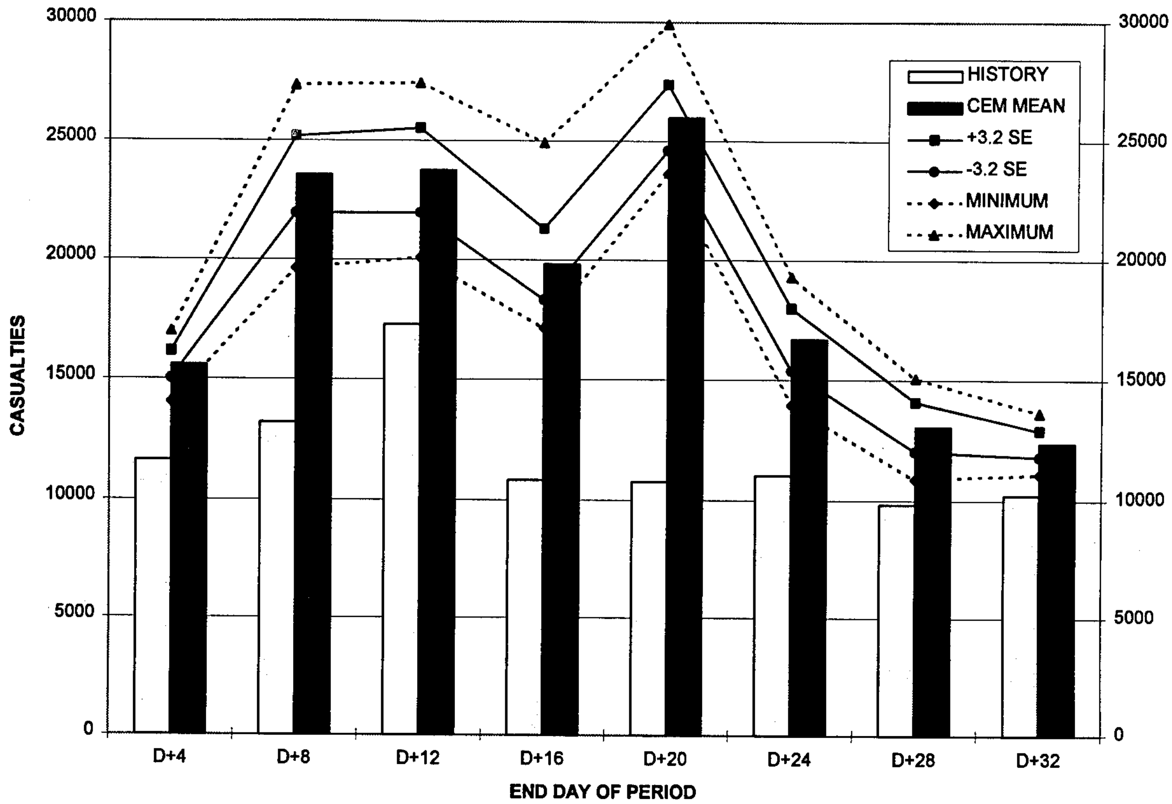


Figure 6-4. German Personnel Losses in Each 4-day Period (STOCEM base case)

Observations derivable from the figures include:

(1) As with US/UK casualties, variability in STOCEM German casualty results is noticeably less (proportionately to its mean) than the variability in STOCEM weapon system losses and FEBA results.

(2) STOCEM tends to consistently produce more casualties than actually occurred. Overall cumulative STOCEM German casualties during the entire campaign were about 44 percent larger than history.

(3) Figure 6-4 shows that the 4-day periods with the greatest STOCEM deviations from history were the periods ending at D+8, D+16, and D+20, when STOCEM generated too many casualties. Since the period ending at D+8 was near the peak of the German attack and since Allies in STOCEM had the largest representation in attack posture during the period ending at D+20, these results may indicate that STOCEM personnel attrition in attack posture is excessive. The overestimation is especially large (140 percent) in the period, ending at D+20, during the peak of the STOCEM US/UK counterattack. These results indicate that the excessive STOCEM personnel attrition in attack posture should be moderated. Such a reduction in personnel attrition

effectiveness during attack would bring the STOCEM German personnel casualties closer to the historical levels.

6-3. US/UK PERSONNEL CASUALTY RATES. Casualty rates from both history and STOCEM were computed only for the US/UK forces in the line units which were available for commitment during the scenario. These line units and their availability dates are those shown in Table 2-2. The casualty rate is defined as [casualties]/[onhand personnel] for all personnel in the line units available for commitment. All personnel in the US/UK line units, including those with noncombat military occupational specialties (MOS), were included. Stratified STOCEM US/UK personnel casualty results, partitioned over casualty types, were assessed and plotted against historical rates for every other day in the scenario. Daily casualty rates are portrayed for KIA, WIA, CMIA, and DNBI in Figures 6-5, 6-6, 6-7, and 6-8, respectively. In addition to the STOCEM average value, the figures show the STOCEM maximum and minimum over the 16 STOCEM replications, along with the 99 percent/90 percent confidence limits (denoted as +3.2 SE and -3.2 SE in the chart). These two pairs of lines form bands which graphically portray the uncertainty in stochastic variation in the STOCEM casualty results.

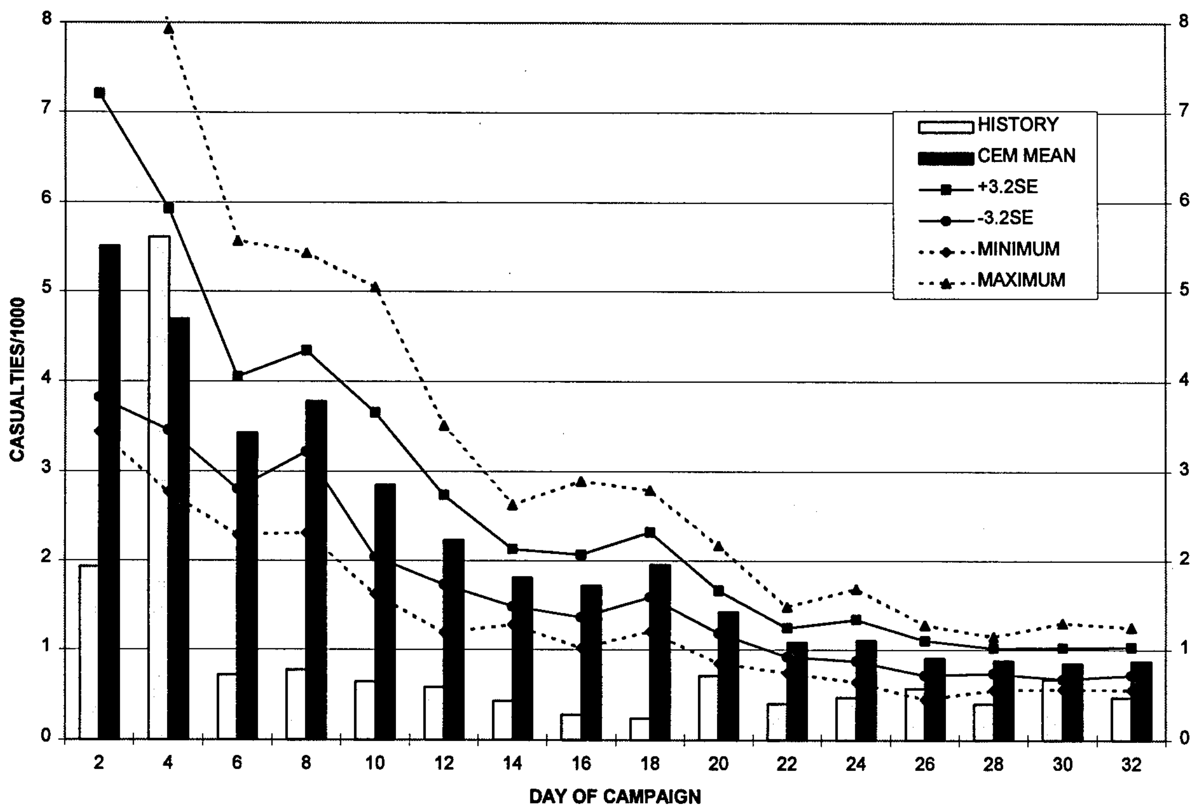


Figure 6-5. US/UK Daily KIA Rate (STOCEM base case)

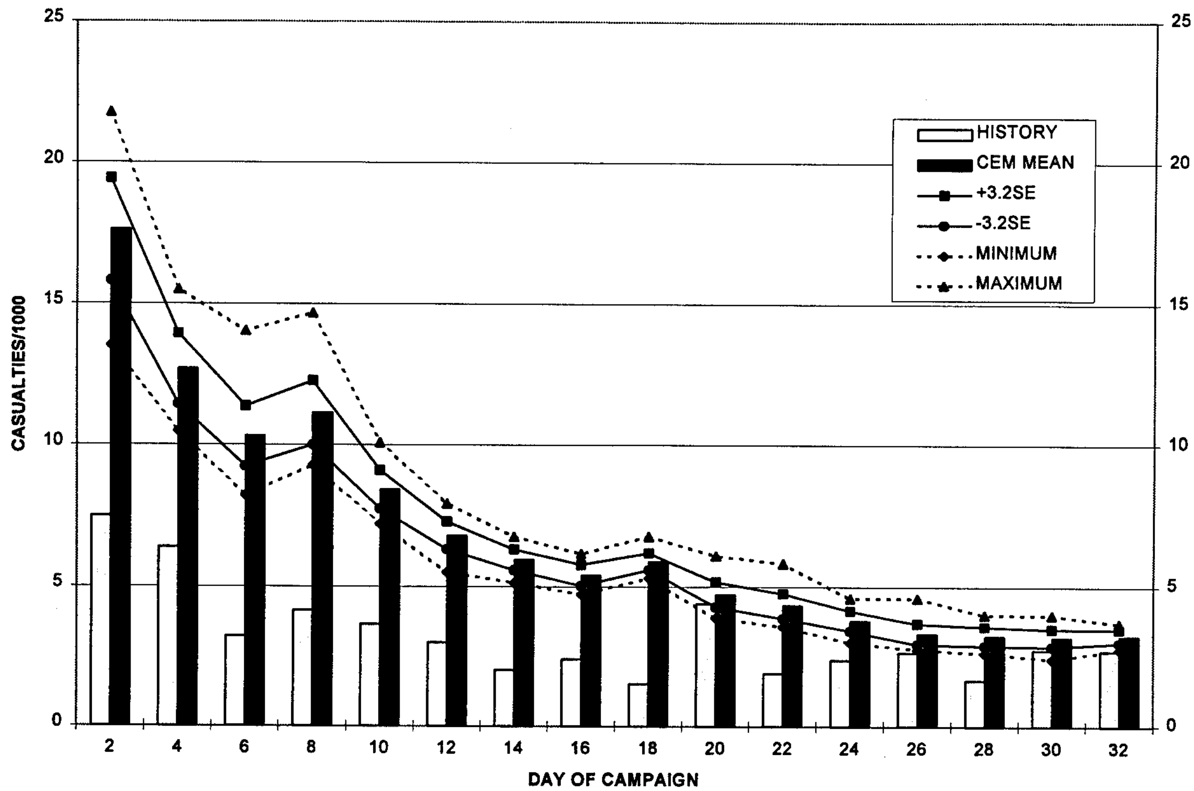


Figure 6-6. US/UK Daily WIA Rate (STOCEM base case)

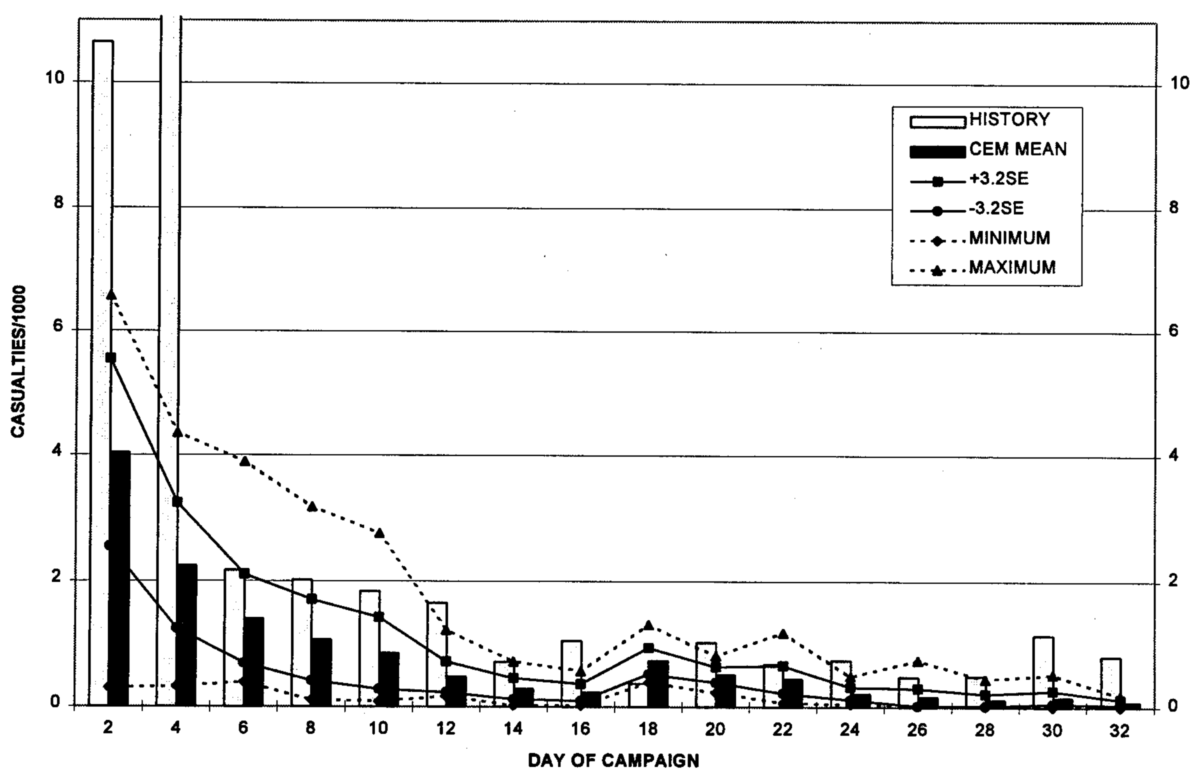


Figure 6-7. US/UK Daily CMIA Rate (STOCEM base case)

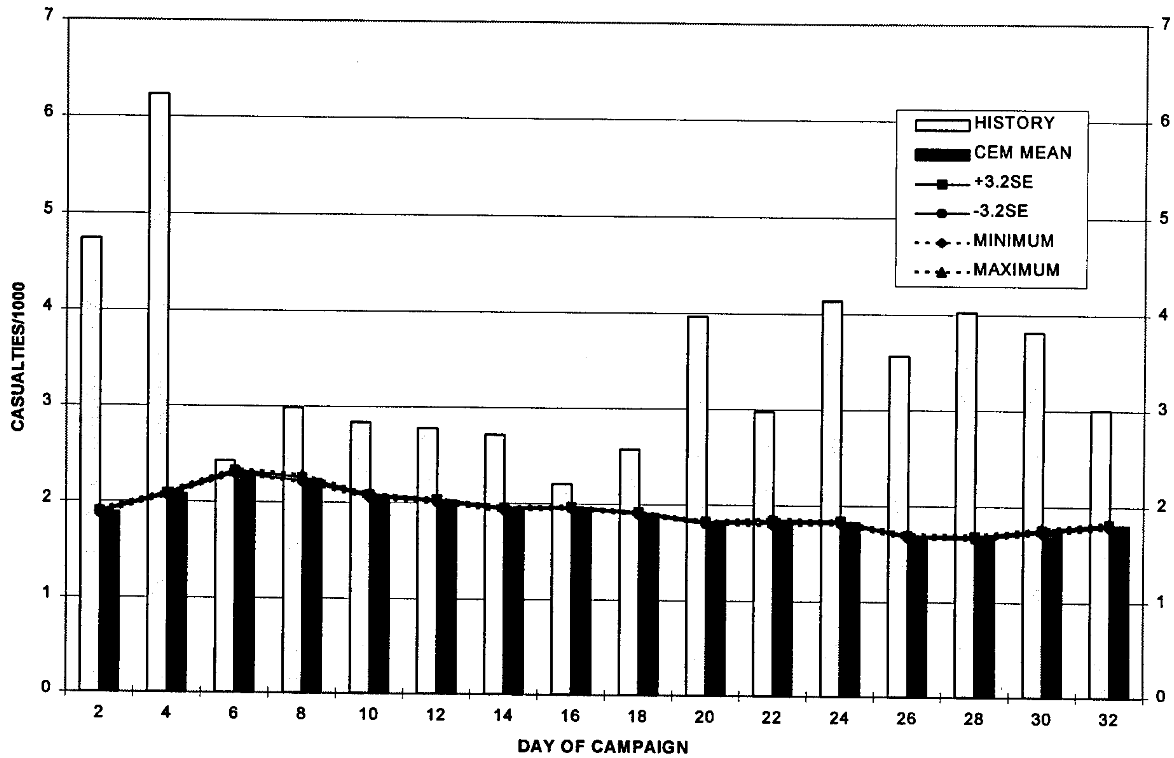


Figure 6-8. US/UK Daily DNBI Rate (STOCEM base case)

Observations derivable from the figures include:

a. Stochastic STOCEM variation is proportionately greatest in the KIA rates and smallest in the DNBI rates.

b. STOCEM consistently overestimates KIA and WIA casualties and underestimates CMIA and DNBI casualties.

c. STOCEM overestimation of both KIA and WIA casualties is noticeably greater in the first half of the campaign.

d. Except for the first 4 days of the campaign, the underestimation of DNBI casualties is noticeably greater in the last half of the campaign.

e. The very large STOCEM underestimation of CMIA in the first 4 days of the campaign reflects the encirclement and surrender, or flight, of much of the US 106th Infantry Division during that period. This exceptional outcome, not modeled by STOCEM, is an effect of the catastrophic breakthrough produced by the initial German attack.

f. The STOCEM DNBI rate is almost constant. In fact, STOCEM does apply a constant input DNBI rate to its casualties. STOCEM essentially applies a constant DNBI rate to total onhand personnel because, based on history and experience, DNBI casualties are generated independent of combat activity of a force. The variability in historical DNBI rate in Figure 6-8 is likely due primarily to noncombat factors (e.g., weather). (The figure does not show an exact constant STOCEM rate because the STOCEM DNBI casualties and onhand force were extrapolated from the infantry/artillery personnel subset simulated in STOCEM to a larger force including all personnel (not just infantry/artillery) in the line units. This extrapolation, described in Appendix H, caused a slight deviation from the constant DNBI rate.)

The above observations are amplified in subsequent paragraphs and figures in this chapter.

6-4. CATEGORY PARTITIONING OF US/UK PERSONNEL CASUALTIES. The total personnel casualties can be partitioned into the following four casualty types: KIA, WIA, CMIA, and DNBI. It is useful to examine and compare the proportions of total STOCEM and historic casualties in each of these categories.

a. Daily Partition of Total Casualties. The partitioning of daily US/UK casualties over the four casualty types was assessed for every other day of the scenario. Figure 6-9 shows the resulting partition of historical total personnel casualties for every other day in the scenario. Figure 6-10 shows the analogous partition for the average (over the 16 replications) STOCEM base case personnel casualties.

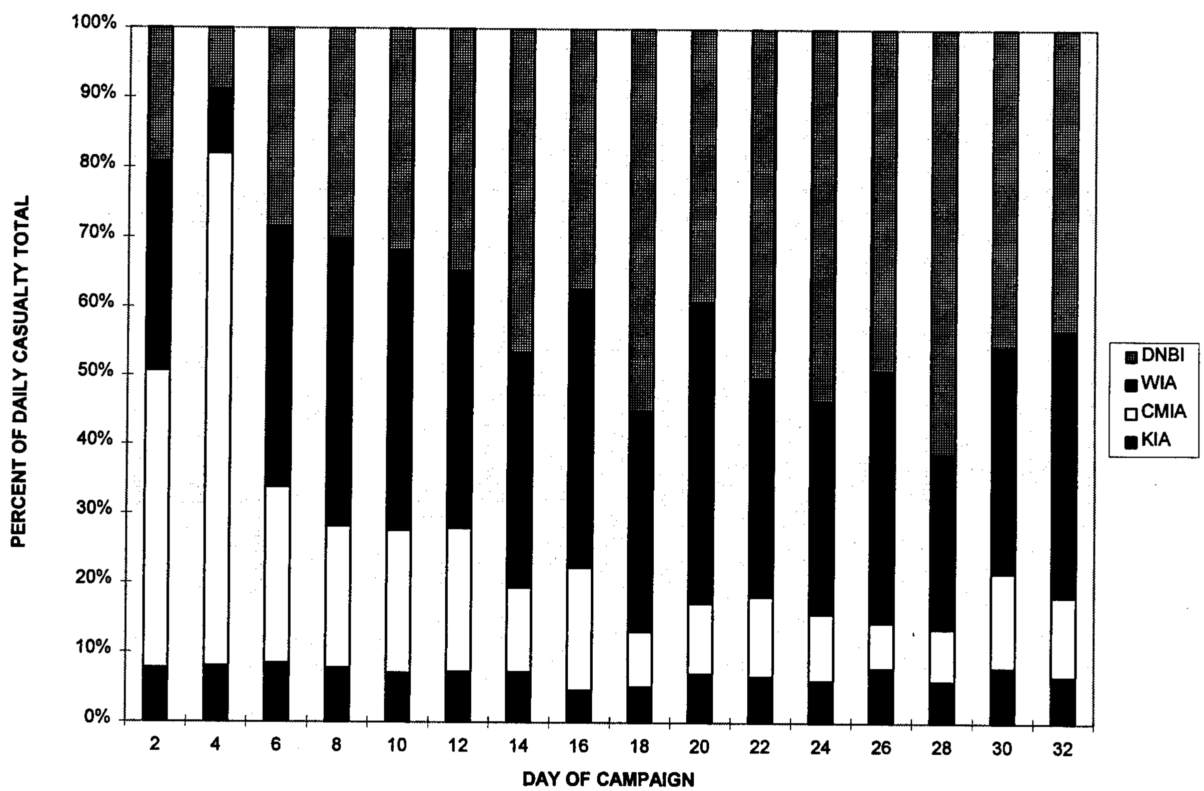


Figure 6-9. Historical Daily Percentage KIA/WIA/CMIA/DNBI in US/UK Total Casualties

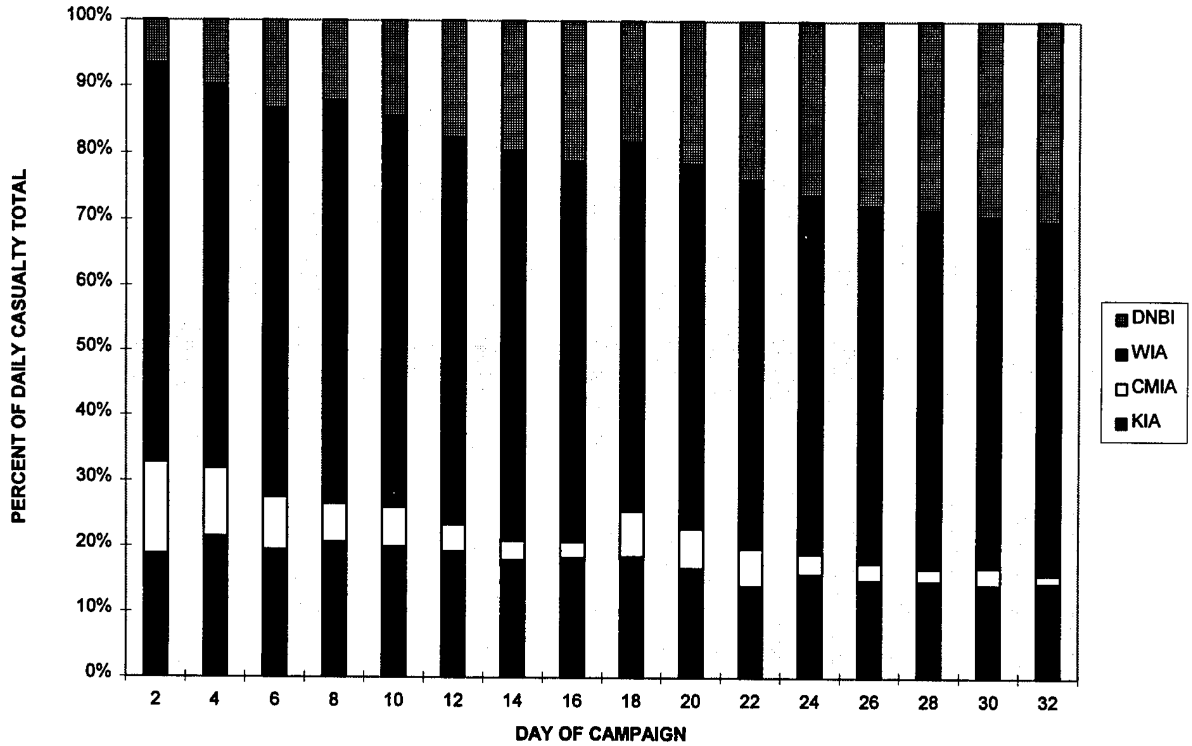


Figure 6-10. STOCEM Average Daily Percentage KIA/WIA/CMIA/DNBI in US/UK Total Casualties (STOCEM base case)

Observations derivable from the figures include:

(1) Historically, WIA usually comprise the largest fraction (of total casualties) during the first half of the campaign while DNBI are the largest fraction during the last half of the time-frame. In STOCEM, WIA consistently account for the largest fraction of personnel casualties.

(2) In both Ardennes history and STOCEM, the DNBI fraction (of total casualties) tends to increase as the campaign progresses. Conversely, the CMIA fraction for both tends to decrease as the campaign progresses. These trends are more consistent in STOCEM.

(3) The STOCEM WIA fraction and the STOCEM KIA fraction are both almost double the corresponding historical fractions.

(4) The STOCEM CMIA fraction and the STOCEM DNBI fraction are both consistently less than the corresponding historical fractions. The STOCEM/history ratio is usually smaller for CMIA than for DNBI.

(5) The very large historical CMIA and DNBI fractions in the first 4 days of the campaign reflect the encirclement, surrender, and/or flight of much of the US 106th ID.

6-5. ANALYSIS OF CASUALTY CATEGORY AVERAGES. While the above charts are descriptive, it is useful to compute and compare STOCEM averages over time with historical averages over time across the four casualty types.

a. Average Fraction KIA/WIA/CMIA/DNBI. The daily fraction of casualties in each casualty type (KIA/WIA/CMIA/DNBI), as plotted in Figures 6-9 and 6-10, was arithmetically averaged over each half of the scenario as well as the entire scenario. This averaging was done only over every other day of the scenario, excluding day 4, which was treated as an atypical outlier because of the enormous CMIA total resulting from the surrender of the 106th ID. Figure 6-11 shows the average historical and STOCEM (base case) fraction casualties in each casualty category during the first half of the STOCEM base case scenario. Figures 6-12 and 6-13 show the analogous historical and STOCEM category averages over the last half of the scenario and over the entire scenario, respectively. The averages in Figure 6-11 are over 7 individual days (days 2, 6, 8, 10, 12, 14, and 16), while those of Figures 6-12 and 6-13 are over 8 and 15 individual days, respectively.

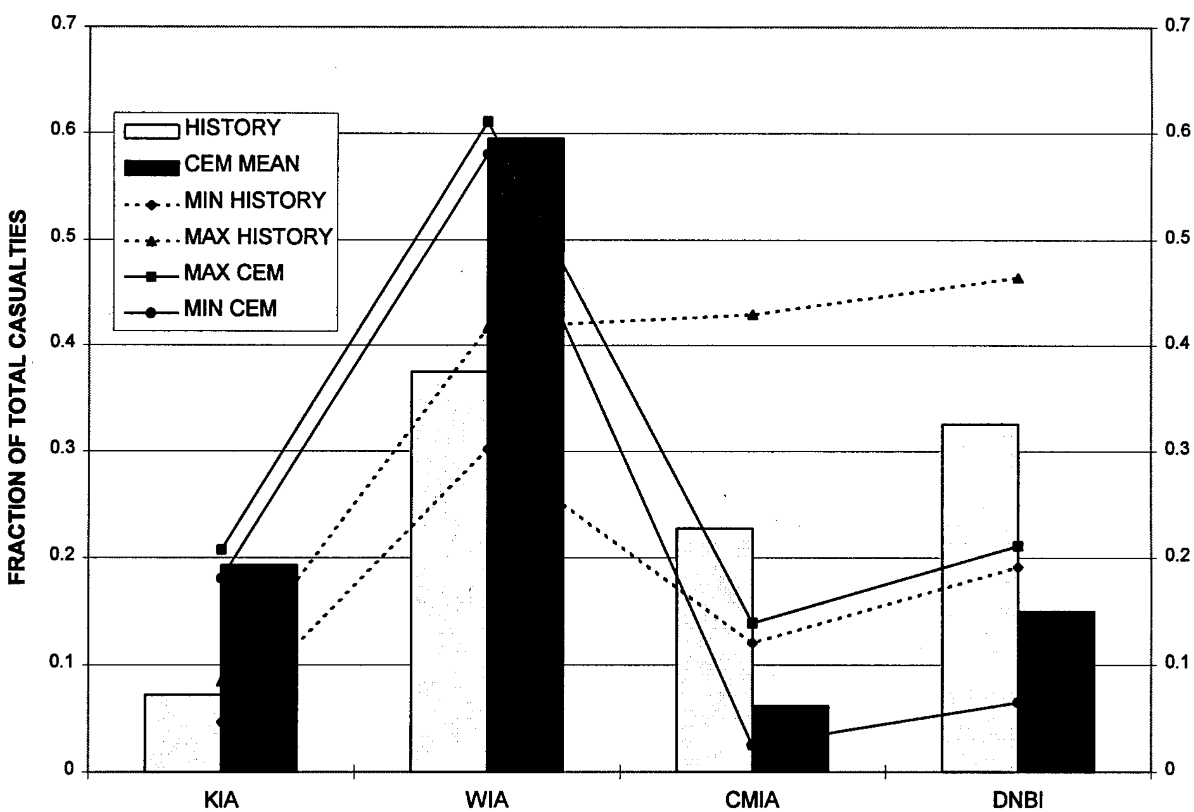


Figure 6-11. Average Daily Fraction KIA/WIA/CMIA/DNBI in Total US/UK Casualties During Days 1-16 (STOCEM base case)

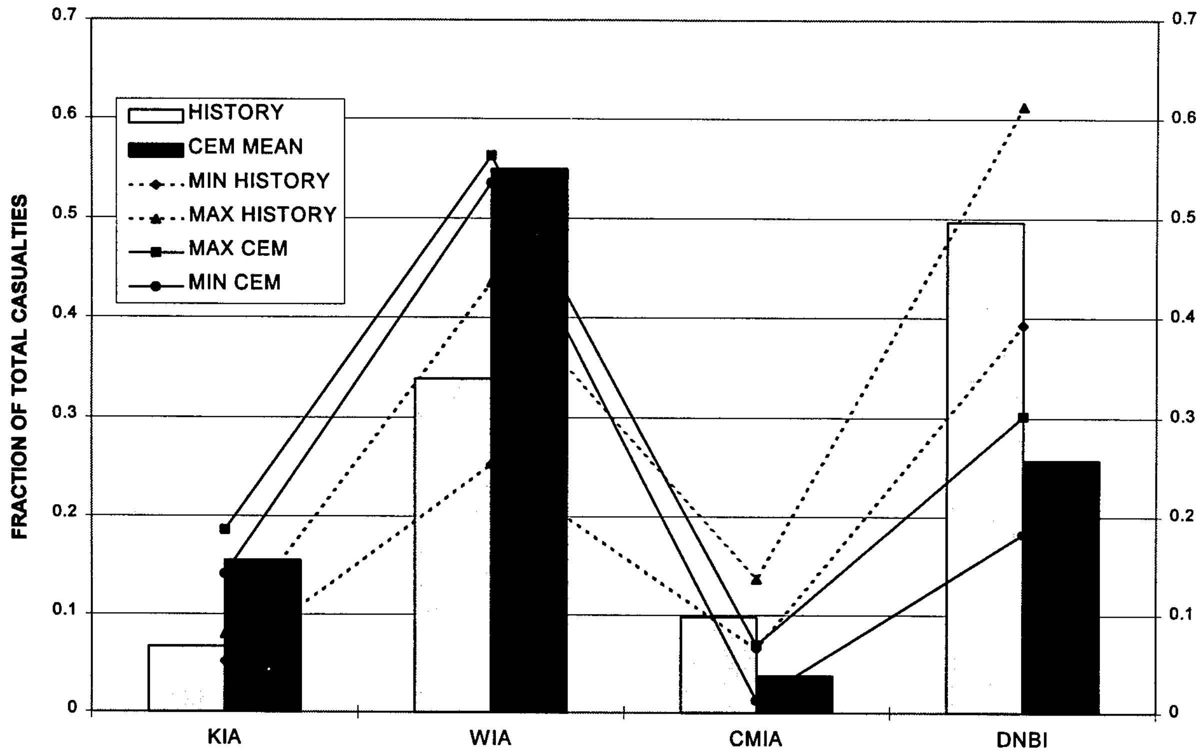


Figure 6-12. Average Daily Fraction KIA/WIA/CMIA/DNBI in Total US/UK Casualties During Days 17-32 (STOCEM base case)

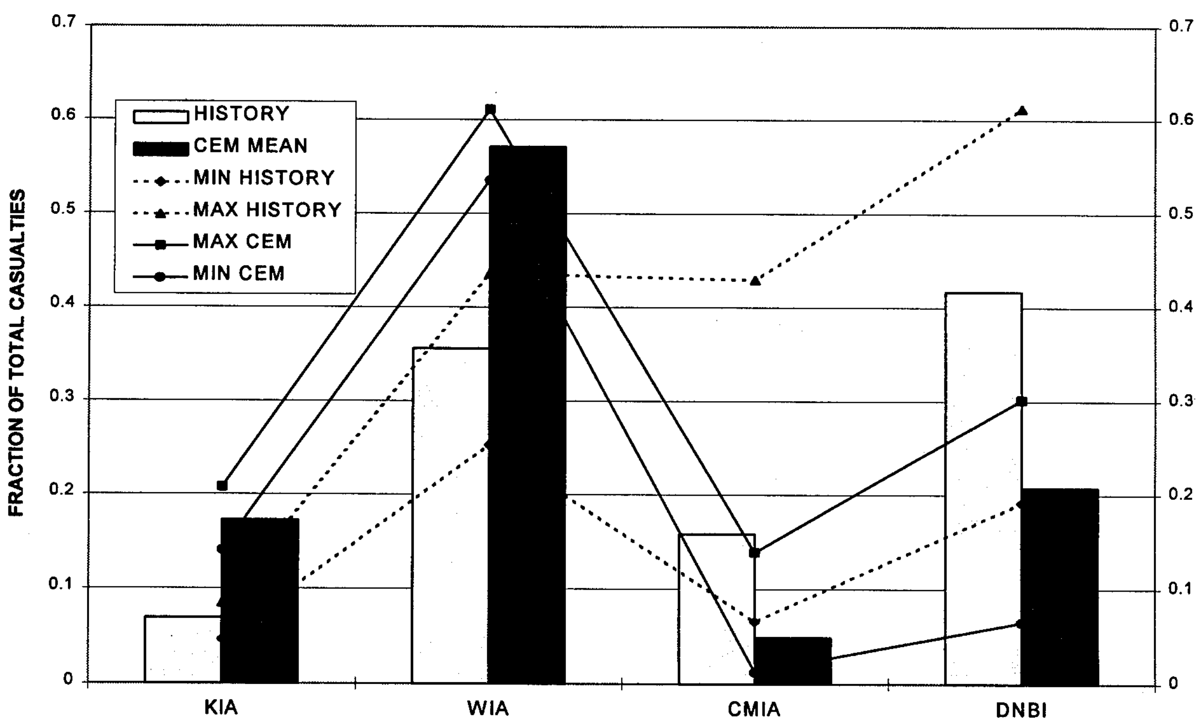


Figure 6-13. Average Daily Fraction KIA/WIA/CMIA/DNBI in Total US/UK Casualties During Campaign (STOCEM base case)

In addition to average casualty fraction over the period, the figures also show the range of values averaged by showing, for both history (points connected by solid lines) and STOCEM (points connected by dashed lines), the maximum and minimum over the individual daily values used in the average. The lines connecting points in the figures are used only to identify the points connected and do not have any quantitative meaning. Note that, for CEM, maximum and minimum do not (as was the case in previous charts) refer to maximum/minimum of individual STOCEM run results over the 16 STOCEM replications, but instead refer to the maximum/ minimum of average (over 16 replications) STOCEM daily casualty fractions over the individual days in the timeframe (excluding day 4). Observations derivable from the figures include:

(1) The observations of paragraph 6-3 apply. The STOCEM average KIA fraction and WIA fraction are almost double the corresponding history values. The STOCEM average CMIA fraction is almost a third of the corresponding historical value, while the STOCEM average DNBI fraction is almost half of the corresponding historical value.

(2) The variation in casualty fraction, as represented by the spread between maximum and minimum, is (proportionately) larger for history values than for STOCEM values and is usually larger over the last half of the scenario (than over the first half).

(3) The KIA and WIA results for the first half of the scenario are similar to corresponding results for the second half of the scenario. The DNBI fraction for both STOCEM and history is substantially increased (about 50 percent) during the last half of the scenario. The CMIA fraction for both STOCEM and history is substantially decreased during the last half of the scenario.

b. Formation of STOCEM Casualty Redistribution Rule. It is possible to construct an approximate rule for redistributing the ARCAS STOCEM personnel casualties into a partition which better "fits" history as follows:

(1) Make the assumption, used in STOCEM, that the DNBI rate is a constant fraction of onhand personnel and is generated independent of combat activity.

(2) Determine a single "best" scaling factor which multiplicatively adjusts STOCEM DNBI to the history DNBI in ARCAS results. Define this scaling factor as the average ratio of [history DNBI rate]:[STOCEM DNBI rate] in Figure 6-8.

(3) For each non-DNBI casualty type (KIA/CMIA/WIA), determine a STOCEM adjustment factor by dividing the associated historical value in Figure 6-13 by the associated STOCEM value.

(4) Compute new adjusted STOCEM casualties, in each casualty type, for each day as follows:

(a) Multiply the unadjusted STOCEM DNBI casualties of each type by the DNBI scaling factor derived above (= 1.727) to get adjusted DNBI casualties for the day.

(b) Subtract the day's adjusted DNBI casualties from the day's total STOCEM casualties to get total adjusted non-DNBI casualties, denoted as total "STOCEM combat casualties" for the day. The proportions of total STOCEM combat casualties in each casualty type will be redistributed in the following steps.

(c) Compute the day's adjusted STOCEM casualties for each non-DNBI casualty type by multiplying the day's unadjusted STOCEM casualties of each non-DNBI casualty type by the adjustment factor derived in (3) above for that casualty type.

(d) Normalize the computations in (c) by multiplying each day's adjusted STOCEM non-DNBI casualty type result by the quantity: [total (unadjusted) STOCEM combat casualties for the day]/[sum of adjusted STOCEM non-DNBI casualties for the day].

(5) The normalized STOCEM non-DNBI casualties are the new adjusted KIA, WIA, and CMIA for the day. The adjusted DNBI casualties in (a) above are the new adjusted DNBI for the day.

This rule simply redistributes the STOCEM casualties over the various casualty types. The DNBI casualties are first adjusted independent of the non-DNBI casualties. Total non-DNBI casualties are then adjusted accordingly and are redistributed among the non-DNBI casualty types.

c. Application of STOCEM Casualty Redistribution Rule. The result of applying the above personnel casualty redistribution logic to Figures 6-8 and 6-13 yields, after slight rounding, the adjustment factors in Table 6-1.

Table 6-1. Casualty Type Adjustment Factors

Casualty type	Adjustment factor
DNBI	1.73
KIA	0.56
WIA	0.86
CMIA	4.0

Application of the casualty redistribution rule, derived in paragraph 6-5b, above, to the base case yields the partition shown in Figure 6-14, which is the "adjusted" version of the unadjusted STOCEM casualty partition shown in Figure 6-10. The distribution of adjusted STOCEM casualties, over the four casualty types, as shown in Figure 6-14 is clearly much closer (than unadjusted STOCEM results) to the historical distribution, which is reflected in Figure 6-9.

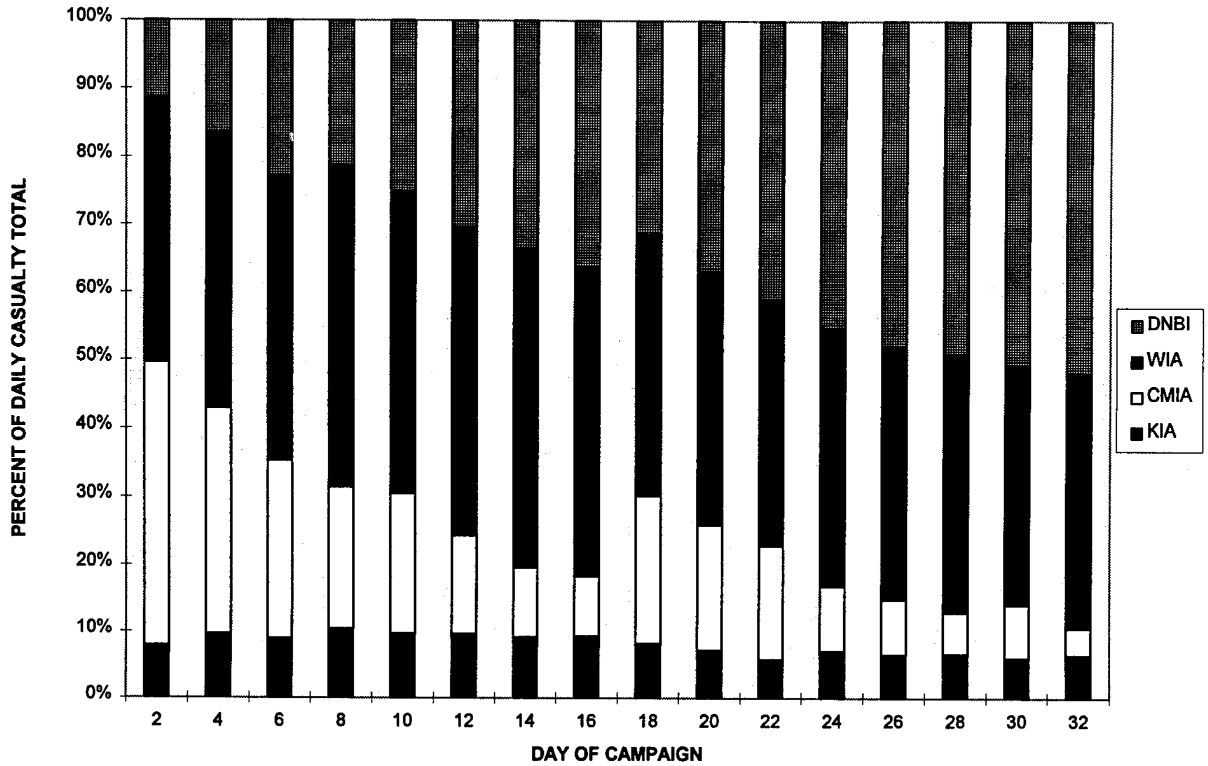


Figure 6-14. Adjusted STOCEM Average Daily Percentage KIA/WIA/CMIA/DNBI in US/UK Total Casualties (STOCEM base case)

d. Effect of STOCEM Casualty Redistribution on Magnitude of Casualties. To further assess effect of the above STOCEM casualty redistribution rule, the magnitude of adjusted STOCEM casualties can be compared with both history and with unadjusted STOCEM casualties. Figure 6-15 shows the average ratio, over every other day of the scenario, of historic casualties to unadjusted base case average STOCEM casualties for each casualty type. (Day 4 is again excluded from the averages because it is treated as a statistical outlier.) The maximum and minimum of the ratio, over the days averaged, is also shown. Figure 6-16 shows the same history vs STOCEM comparison after the STOCEM casualties have been adjusted with the rule defined in paragraph 6-5b. In both figures, the closer the [history/STOCEM] ratio is to 1.00, the better is the STOCEM casualty estimate.

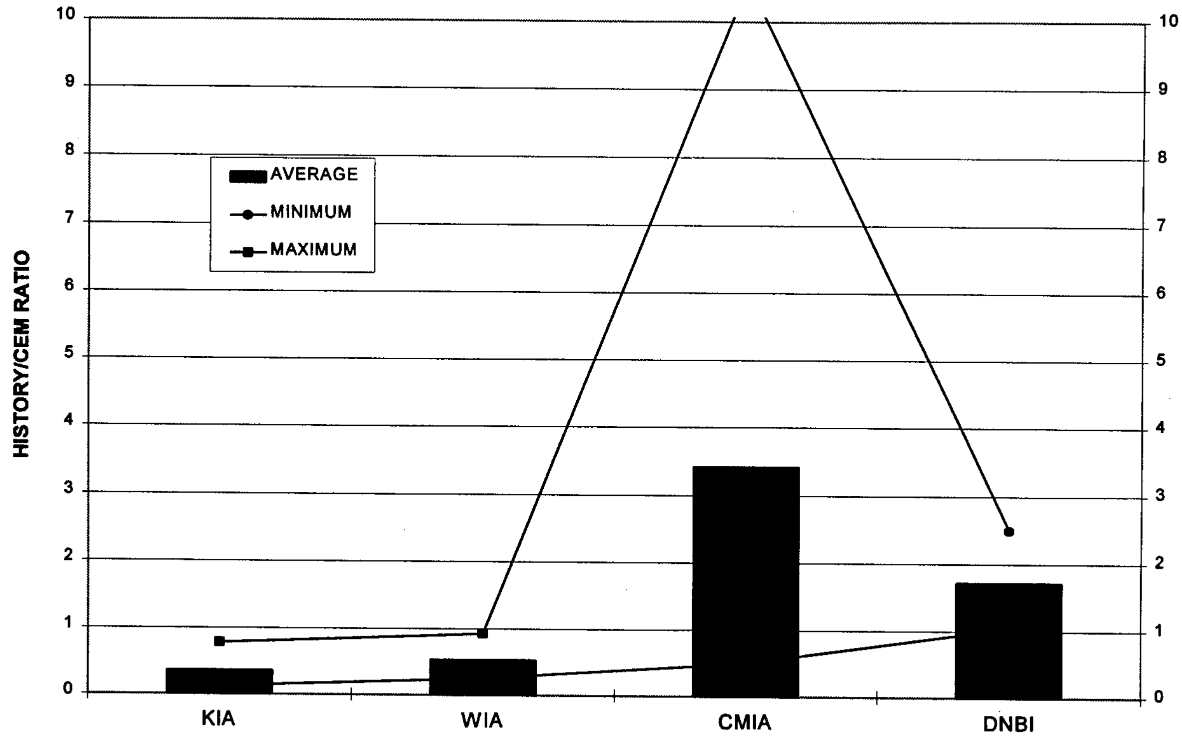


Figure 6-15. Unadjusted History vs STOCEM Casualty Ratios for US/UK (STOCEM base case)

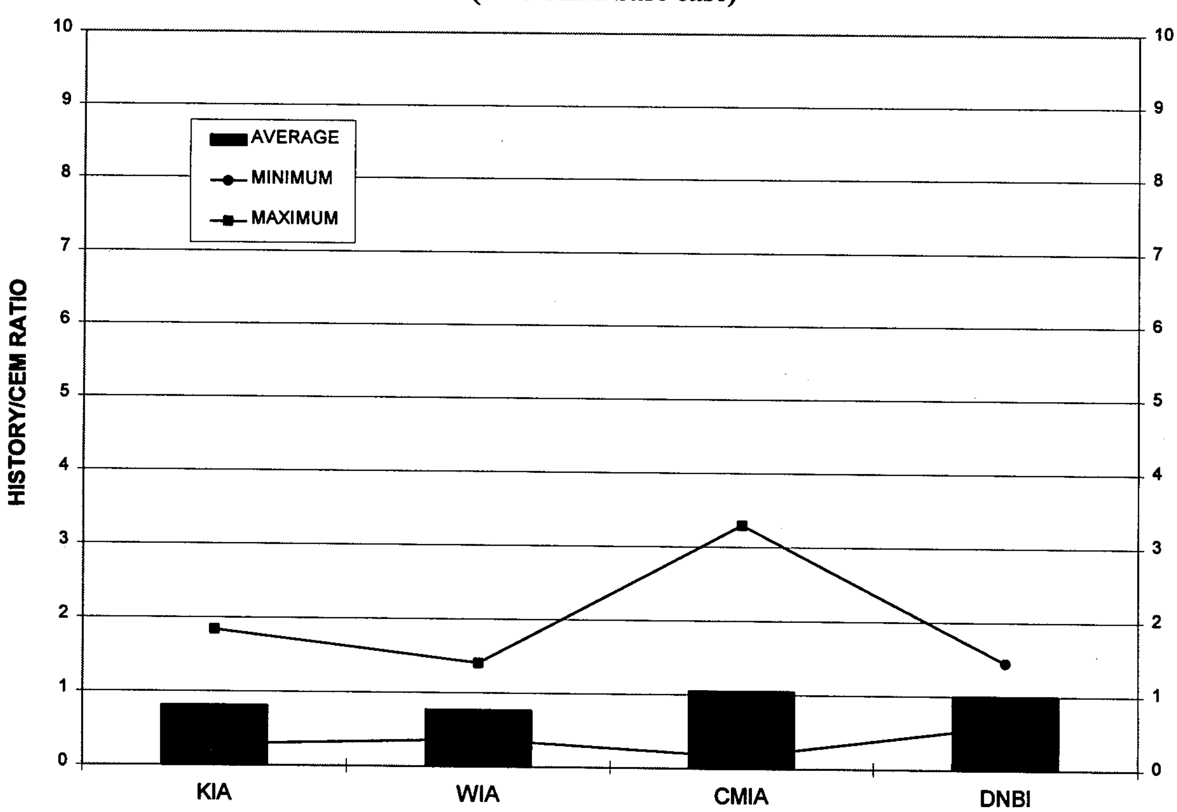


Figure 6-16. Adjusted History vs STOCEM Casualty Ratios for US/UK (STOCEM base case)

Observations derivable from the figures include:

(1) The unadjusted STOCEM mean daily KIA and WIA casualties consistently overestimate the historical (Ardennes) casualties. Conversely, the unadjusted STOCEM mean daily DNBI casualties consistently underestimate historical casualties. No casualty type has the average STOCEM casualties close to the average historical casualties. In the best case, the average [history/STOCEM] casualty ratio for WIA is .62. In the worst case (CMIA), it is 3.87.

(2) The DNBI scaling adjustment factor was defined in such a way that the average History vs STOCEM DNBI casualty ratio must equal 1.00. After the application of the STOCEM personnel casualty redistribution rule, defined in paragraph 6-5b, above, to STOCEM casualties, the average adjusted STOCEM casualties are close to the average historical casualties for each of the other three casualty types. The average [history/STOCEM] casualty ratios range between .77 (for WIA) to 1.05 (for CMIA). (Averages are taken over the scenario timeframe.)

(3) Although the adjusted STOCEM casualties are close to history when averaged over the scenario, there is considerable dispersion in the closeness of the daily values, as reflected in the maximum and minimum in Figure 6-16. This dispersion is greatest for CMIA, with daily casualty ratios varying between .16 and 3.29, and is smallest for DNBI, with ratios between .61 and 1.45.

6-6. STOCEM EXCURSION CASE RESULTS. Appendix H contains a complete set of personnel casualty results for the STOCEM excursion case scenario, including an exact analogue of each STOCEM base case chart displayed in this chapter. In general, the STOCEM excursion case resulted in slightly more casualties than the STOCEM base case, with the largest differences occurring during the first half of the campaign, especially during the first 8 days.

6-7. SUGGESTED STOCEM MODIFICATIONS

a. Reduction of Lethality in Attack Posture. The STOCEM German personnel casualty results, in conjunction with the STOCEM US/UK engagement posture profiles, yielded indications that STOCEM may kill an excessive number of German personnel when a substantial part of the US/UK force is in attack posture. It would appear that, in the "real world," the attacking US/UK force in the historical campaign inflicts German casualties at lower rates, over time, than is reflected in the current STOCEM algorithms. A reduction of an attacking force's STOCEM lethality against personnel may be appropriate. The CAA CEM maintenance staff should examine whether, and if appropriate, how, the ATCAL attrition logic of STOCEM could be modified to incorporate this lethality reduction process. The need to modify inputs and logic in the COSAGE preprocessor should also be assessed.

b. Revised Partitioning of Personnel Casualties over Casualty Types. The average, over the scenario, daily STOCEM casualty percentages in each casualty category (KIA/WIA/CMIA/DNBI) differed by 50 percent or more from the corresponding historical percentage. On a daily basis, the STOCEM average casualties for two casualty types (CMIA and DNBI) consistently underestimate history. Redistribution of ARCAS STOCEM casualties over the four casualty types appears appropriate. A casualty redistribution rule was devised by using the observed differences between historical and ARCAS STOCEM results to develop a multiplicative adjustment factor for each STOCEM casualty type. These adjustment factors are those shown in Table 6-1. Application of the casualty redistribution rule consists of adjustment of current STOCEM personnel casualties through multiplication by the associated adjustment factor, followed by normalization to make total adjusted casualties equal to the total unadjusted STOCEM casualties. Application of the redistribution rule produced a considerably closer fit of ARCAS STOCEM US/UK casualty type results to those of history. This improvement is a measure of "goodness of fit" rather than "goodness of prediction" and is not necessarily valid as a predictor of future usefulness in other scenarios. However, since application of the above casualty redistribution rule is useful for the ARCAS scenario, it, or variants of it, should be examined for more general use in the STOCEM processor logic which partitions personnel casualties.

c. Simulation of Catastrophic Breakthrough Effects. The occurrence of the extremely large historical US/UK CMIA casualties in the initial 4 days of the campaign is an effect of the "catastrophic breakthrough" nature of the initial German attacks. In a breakthrough, the rapid advance of an overwhelming force greatly increases the likelihood, and occurrences, of small unit encirclements, mass surrender, and disorganized retreat. This breakthrough effect was also noted in the Chapter 5 observations on weapon system losses. The current CEM (and STOCEM) does not model such a breakthrough effect. Methods should be investigated to reduce this bias by modifying CEM to enable application of a "breakthrough" combat attack posture, related to attacker speed and overwhelming attacker force advantage, which generates significantly accelerated CMIA (and possibly DNBI) defender casualties.

CHAPTER 7

FINDINGS AND OBSERVATIONS

7-1. PURPOSE. The purpose of this chapter is to address the essential elements of analysis required of the study and to state key findings and observations, with suggestions for modifying STOCEM input and logic. Suggestions for follow-on work are also given.

7-2. SCOPE

a. Limitations. A recommendation presented herein is usually only a possible or probable course of action which may be neither the best, nor the only, proposal, in light of the information presented in associated charts and graphs. That, however, does not preclude the possibility of further development and/or quantification of results/recommendations in follow-on efforts.

b. Applicability to CEM. Recommendations developed in ARCAS, although based on STOCEM applications, may also be applicable to CEM applications because STOCEM is just a stochastic version of the deterministic CEM XI simulation. STOCEM and CEM have the same scenario inputs and combat event logic.

7-3. ESSENTIAL ELEMENTS OF ANALYSIS (EEA). The study directive specifies the following EEA, which are presented with a summary of the responses which resulted from the study.

a. What major similarities and differences in critical elements exist between the ARCAS STOCEM results of the Ardennes Campaign and the historical record of that battle?

(1) Similarities

(a) FEBA Progress. During most of the first half of the campaign, history and ARCAS STOCEM produced similar FEBA movement in the theater area comprising the historic "bulge." In both the base case and the excursion case, the bulge in the STOCEM-processed average FEBA for D+8 shows a distinct configurational similarity to the historical bulge both in extent and area.

(b) Ammunition Expenditure. STOCEM US/UK cumulative expenditure tonnage results in the ARCAS base case are similar to historical in both trend and magnitude, especially over the first 28 days of the campaign.

(c) Weapon System Losses. Both US/UK and German cumulative ARCAS STOCEM tank losses are usually very similar to historical losses during the first half of the campaign. Both STOCEM and historical US/UK artillery losses are negligibly small after D+12.

(d) Personnel Losses. The historical total US/UK casualties appear to be similar to the average STOCEM-processed total casualties both in magnitudes and trend. In both history and ARCAS STOCEM, the DNBI fraction (of total casualties) tends to increase as the campaign progresses. Conversely, the CMIA fraction for both tends to decrease as the campaign progresses. These trends are more consistent in STOCEM results.

(2) Differences

(a) FEBA Progress. On average, the ARCAS STOCEM FEBA advances too rapidly (relative to history) in the first 4 days and, after D+16, the counterattacking US/UK force induces a German retreat with a considerably faster retrograde movement than occurred historically.

(b) Ammunition Expenditure. The STOCEM-processed German ammunition tonnage expended is much larger than history.

(c) Weapon System Losses

1. The historical cumulative US/UK APC and AT/M system losses exhibit a consistent and marked tendency to "level off" after the historical German "high water mark" is reached around D+8. The ARCAS STOCEM results do not exhibit such a marked leveling off.

2. ARCAS STOCEM results have many more APC and AT/M system kills than occurred in history, especially after D+8.

3. STOCEM-processed US/UK artillery losses during the first 12 days of the campaign are negligible, compared to historical losses of 195 tubes in that period. STOCEM German artillery kills over the whole campaign are almost half the number of historical kills.

(d) Personnel Losses

1. For both the US/UK and the Germans, ARCAS STOCEM results have more total casualties than actually occurred historically. This overestimate is substantially greater for German casualties. Overall cumulative STOCEM US/UK casualties during the entire campaign were about 12 percent larger than history, while the corresponding German casualties were about 44 percent larger than history.

2. Historically, WIA usually comprise the largest fraction of total US/UK casualties during the first half of the campaign while DNBI are the largest fraction during the last half of the timeframe. In ARCAS STOCEM results, WIA consistently account for the largest fraction of US/UK personnel casualties.

3. For the US/UK force, the STOCEM-processed average KIA fraction and WIA fraction are almost double the corresponding history values. The STOCEM average CMIA fraction is almost a third of the corresponding historical value, while the STOCEM average DNBI fraction is almost half of the corresponding historical value.

b. What appear to be the causes of the differences between simulation results and those from the historical battle records?

Each rationale noted below is categorized according to whether its primary dependency is on model logic/processes or on input value settings for models (STOCEM, COSAGE).

(1) FEBA Progress. Possible reasons for the move rate differences include:

(a) Logic-dependent. The placement and concentrations of forces generated by a fully automated model, such as STOCEM, may well achieve a stronger rollback of a weaker opponent than can be achieved by a less efficient and more cautious actual force. An actual combat force probably deploys its units less effectively than the STOCEM algorithms, and, affected by human factors reflecting "real-world" uncertainty, moves with more deliberation than is reflected in its potential. The STOCEM logic consistently reinforces and exploits success in attack with relentlessly consistent and efficient algorithmic rules, unlike decisions and actions in "real life."

(b) Input-dependent. The ARCAS STOCEM move rate inputs are too high because they reflect a potential movement capability not generally achievable in real combat. Actual combat movement is also degraded by tactical, weather, and logistical considerations that are not explicitly modeled by STOCEM.

(2) Ammunition Expenditure

(a) Logic-dependent. The excessively large German ARCAS STOCEM ammunition tonnage expended is due, in part, to the inability of the STOCEM to model exceptional logistical circumstances causing road/rail congestion and transport shortages during the historical campaign.

(b) Input-dependent. A contributor may be underestimation of single round ammunition weight inputs and ammunition expenditure factor inputs to STOCEM. If the ratio of history expenditure/ STOCEM expenditure is used to multiplicatively adjust the magnitudes of all STOCEM German ammo expenditure results, then the adjusted STOCEM results are much closer to history in both magnitude and trend. The German records may also be incomplete or inconsistent.

(3) Weapon System Losses

(a) Logic-dependent

1. STOCEM appeared to be more aggressive in its employment of tanks and engaged them more closely and more frequently than did history. The historical cumulative US/UK tank losses may level off over time because the historical US/UK force may well have been more conservative in allowing risks to its weapon systems after sustaining an assault as surprisingly devastating as the first part of the Ardennes offensive.

2. Examination of US/UK attack posture frequency, in conjunction with large discrepancies (between STOCEM and history) indicates that a STOCEM defender's armor attrition, inflicted by an attacking force, may be excessive.

3. The most plausible explanation for the very low historical APC and AT/M losses after D+8 is a cautionary usage policy which kept the APCs from being sufficiently exposed to enemy weapon systems after the main German offensive was blunted. This was feasible, since the US/UK were on the offensive after D+16 and had sufficient strength to keep from being overrun. Such a conservative system use policy was apparently not reflected in STOCEM logic or decision thresholds in the ARCAS scenario.

4. The large difference (between ARCAS STOCEM and history) in number of US/UK artillery systems killed reflects the catastrophic breakthrough of the initial German advance, which is not modeled in STOCEM. Both history and STOCEM show negligible US/UK artillery losses if the effects of this catastrophic breakthrough are discounted.

(b) Input-dependent

1. Vulnerability and/or exposure of these systems, reflected in COSAGE inputs, may also have been overestimated. Weapon system lethality/vulnerability input data in COSAGE drive the killer-victim tables used by STOCEM to calculate attrition.

2. The excess of ARCAS STOCEM over historical artillery losses may also reflect some underestimation of artillery vulnerability/exposure in inputs to COSAGE.

(4) Personnel Losses

(a) Logic-dependent

1. Examination of US/UK attack posture frequency, in conjunction with deviations of ARCAS STOCEM casualties from historical casualties, indicates that a STOCEM defender's personnel attrition, inflicted by an attacking force, may be excessive.

2. The average, over the ARCAS scenario, daily STOCEM casualties in each casualty category (KIA/WIA/CMIA/DNBI) differed by 50 percent or more from the

corresponding historical percentage. The STOCEM logic which partitions total casualties into casualty categories may need to be reevaluated and revised.

(b) Input-dependent. The excessive ARCAS STOCEM casualties may also be due, in part, to excessively high personnel vulnerability inputs.

c. What implications on the validity of the STOCEM theater combat simulation process can be derived from the comparison of ARCAS STOCEM results with those from history?

(1) FEBA Progress. ARCAS base case STOCEM maximum FEBA penetration was very similar to history and was greater than the maximum FEBA advance for the ARCAS STOCEM excursion case. These results support the credibility of the STOCEM representation of combat and movement.

(2) Ammunition Expenditure

(a) The similarities, in both trend and magnitude, of ARCAS STOCEM and historical US/UK ammunition expenditures support the credibility of the STOCEM representation of US/UK ammunition tonnage expenditure. Historical and STOCEM German cumulative ammunition expenditures are very similar, in both magnitude and trend, after a constant multiplicative scaling adjustment is applied to STOCEM ammunition round weight inputs.

(b) The higher excursion case US/UK ammunition expenditure is plausible, since reinforcing units in the excursion case are allocated to the "neediest" sectors in theater, where they would likely confront more opposition (and targets) than in the base case which restricted reinforcing units to their historically supported sectors. The differences are credible.

(3) Weapon System Losses. ARCAS STOCEM tank and APC losses are similar to historical values during the first half of the campaign. If the catastrophic breakthrough effects of the initial German attack, not amenable to modeling, are discounted, then both history and STOCEM show negligible US/UK artillery losses. These similarities all give support to STOCEM model credibility.

(4) Personnel Losses. The similarities between ARCAS STOCEM and history in magnitude and trend of cumulative ARCAS STOCEM total casualties over time give support to STOCEM model credibility. The trend similarities between STOCEM and history in US/UK DNBI fraction and CMIA fraction also enhance the credibility of the STOCEM combat representation.

d. What changes in STOCEM, the kind of inputs it uses, or the way the model is applied are suggested by this comparison as appropriate for future simulations?

Each suggested modification noted below is categorized according to whether its primary dependency is on model logic/processes or on input value settings for models (STOCEM, COSAGE).

(1) **FEBA Progress**

(a) **Logic-dependent**

1. **Moderation of Movement in a Sustained Attack/Advance.** ARCAS results indicate that STOCEM logic should be able to represent a sustained rapid force advance punctuated by intervals of reduced mobility and aggressiveness. Methods should be investigated which moderate the CEM-calculated move rate capability (in selected force postures) in response to a "sufficiently sustained" rapid combat advance. One possible approach is for STOCEM to assess, in each 12-hour cycle, how long a force has been in an attack posture and to subsequently reduce the CEM-calculated move rate in proportion to the assessed attack posture duration. Consideration should also be given to reducing the basic CEM input move rates in the attack posture.

2. **Fixing Force Closure on an Objective.** In STOCEM, movement, up to 10 km, past the user-set force objective occurs during the (up to 12-hour) period just before the STOCEM status check which "senses" achievement of that objective. It seems more nearly correct and appropriate if each STOCEM unit can be programmed to stop at the objective positions. Ways to accomplish this should be devised and tested.

(b) **Input-dependent.** Consideration should also be given to reducing the basic ARCAS STOCEM input move rates in the attack posture.

(2) **Ammunition Expenditure (Input-dependent).** The ARCAS input German ammunition round weights should be reevaluated to determine whether revised and corrected weights will generate German ammunition expenditure results closer to historical in the ARCAS scenario.

(3) **Weapon System Losses**

(a) **Logic-dependent**

1. **Reduction of Lethality in Attack Posture.** ARCAS results indicate that, in the "real world," an attacking force may well kill more conservatively, over time, than is reflected in the current STOCEM algorithms. A reduction of an attacking force's basic STOCEM lethality against enemy tanks and APCs appears appropriate, with a higher reduction associated with a higher strength advantage (for the attacker). The CAA CEM maintenance staff should examine whether and, if appropriate, how, the ATCAL attrition logic of CEM could be modified to incorporate this lethality reduction process.

2. **Simulation of a Conservative Use of Mechanized Weapon Systems.** In the case of US/UK APC and AT/M losses, the most plausible explanation for the very high concentration of historical losses of US/UK mechanized weapon systems (APCs and AT/Ms) in the first 4 days indicates that the US/UK probably followed a cautionary usage policy which successfully kept these systems from being exposed to any significant enemy fire after the main

German offensive was blunted. STOCEM should be able to simulate such a "conservative use" policy for a force's mechanized weapon systems. The STOCEM logic should probably be modified to allow a reduction in the currently computed ATCAL vulnerability of mechanized weapon systems under appropriate circumstances. These circumstances should probably include having recently sustained a period of heavy losses in defense, while currently possessing a sufficient strength advantage to prevent an enemy advance or counteroffensive.

(b) Input-dependent. Reduce ARCAS input vulnerability of armor and AT/M systems. Increase input vulnerability of artillery systems.

(4) Personnel Losses

(a) Logic-dependent

1. Reduction of Lethality in Attack Posture. An attacking US/UK force in the ARCAS scenario historically appears to kill German personnel more conservatively, over time, than is reflected in current STOCEM algorithms. A reduction of a STOCEM attacking force's lethality against personnel seems appropriate. The CAA CEM maintenance staff should examine whether and, if appropriate, how the ATCAL attrition logic of CEM could be modified to incorporate this lethality reduction process.

2. Revised Partitioning of Personnel Casualties Over Casualty Types. Redistribution of STOCEM casualties over the four casualty types appears appropriate and necessary. A casualty redistribution rule was developed by using the observed differences between historical and STOCEM results to develop a multiplicative adjustment factor for each STOCEM casualty type. Application of this redistribution rule produced a much closer fit of STOCEM US/UK casualty type results to those of history. This rule, or variants of it, should be examined for more general use in the STOCEM processor logic which partitions personnel casualties.

(b) Input-dependent. Consideration should also be given to reducing ARCAS input vulnerabilities of personnel.

7-4. SUMMARY OF KEY FINDINGS. The key findings from the comparison of the STOCEM simulation of the Ardennes Campaign (ARCAS) with history are summarized in Table 7-1. They include:

a. FEBA Movement. During most of the first half of the campaign, history and STOCEM produced similar FEBA movement in the theater area comprising the historic "bulge." During the first 4 days and in the US/UK counteroffensive in the last half of the campaign, the FEBA movement in ARCAS STOCEM was much faster than history.

b. Ammunition Expenditure

(1) ARCAS STOCEM US/UK tonnage expended is similar to history.

(2) ARCAS STOCEM German tonnage expended is considerably higher than history.

c. Weapon System Losses

(1) Cumulative ARCAS STOCEM tank losses and German APC losses are similar to history during the first half of the campaign.

(2) ARCAS STOCEM AT/M losses and US/UK APC losses are much higher than history. After D+8, historical US/UK APC and AT/M losses are negligible.

(3) ARCAS STOCEM artillery losses are much lower than historical losses, but US/UK losses are negligible in both STOCEM and history if catastrophic breakthrough effects present in the historical campaign, but not amenable to modeling, are discounted.

d. Personnel Losses

(1) ARCAS STOCEM cumulative total US/UK casualties are similar to history both in magnitude and trend.

(2) ARCAS STOCEM cumulative total German casualties are greater than history.

(3) The ARCAS STOCEM distribution of casualties over casualty types has too large a proportion of KIA and WIA and too low a proportion of CMIA and DNBI.

Overall, a force modeled in ARCAS STOCEM tends to move faster than history and to lose both personnel and weapon systems, excepting artillery, at a somewhat faster rate than (Ardennes) history, especially when a large part of the force is attacking.

Table 7-1. Summary of ARCAS vs History Comparisons

Outcome type	Similarities: ARCAS vs history	Differences: ARCAS vs history
FEBA	(1) Maximum FEBA advance (2) FEBA "bulge" configuration	Faster movement in ARCAS
Ammunition expenditure	US/UK tonnage expended	Much higher German tonnage expended in ARCAS
Tank losses	Losses in first 16 days of scenario	Excessive ARCAS losses in last 16 days
APC losses	German losses	Excessive ARCAS US/UK losses
AT/M losses		Excessive ARCAS losses
Artillery losses	US/UK losses when catastrophic breakthrough effects are discounted	Considerably lower ARCAS losses
Personnel lost	(1) US/UK total casualties (2) DNBI and CMIA trends over time	(1) Excessive ARCAS total German casualties (2) Proportion of ARCAS KIA and WIA too large (3) Proportion of ARCAS CMIA and DNBI too low

7-5. OBSERVATIONS ON ARCAS STOCEM/HISTORY COMPARISONS. Additional observations derived from the ARCAS STOCEM/history comparisons include:

a. Historical Logistics Constraints on German Ammunition Expended. The excessive ARCAS STOCEM German ammunition expenditure is due, in part, to exceptional logistical circumstances not modeled in STOCEM, causing road/rail congestion and transport shortages during the historical campaign.

b. Conservation of US/UK Weapon Systems. The negligible historic US/UK APC and AT/M losses after D+8 suggest a successful US/UK policy of conserving mechanized systems by reducing their vulnerability and exposure after D+8.

c. Excessive STOCEM Movement and Losses While Attacking. For movement, non-artillery weapon losses, and personnel casualties, ARCAS STOCEM divergence from history tends to be larger in the first few days of the campaign and when the US/UK is counterattacking in the last half of the campaign. These results indicate a tendency for STOCEM to generate excessive movement, system losses, and casualties while attacking.

7-6. KEY STOCEM INPUT/LOGIC MODIFICATION SUGGESTIONS. The key areas of investigation for CEM input and logic modification derived from the ARCAS STOCEM/history comparisons are summarized in Table 7-2. Specific suggestions, categorized as primarily logic-driven or input-driven include:

a. FEBA Movement

(1) Logic-driven

(a) Investigate methods which moderate the CEM-calculated move rate capability (in selected force postures) in response to a "sufficiently sustained" rapid combat advance. That is, simulation realism appears to require a "pause" to be programmed into STOCEM movement following multiple successive time periods (cycles) of continual attack activity by the same unit.

(b) Modify CEM logic to force each STOCEM unit to stop at input-specified objective positions. (Current CEM permits movement up to 10 km beyond objectives.)

(2) Input-driven. Investigate reducing ARCAS input move rates for the attacker.

b. Ammunition Expenditure (Input-driven). Reevaluate ARCAS input German ammunition round weights and investigate revising them as required.

c. Weapon Losses

(1) Logic-driven

(a) Investigate methods which reduce an attacking force's basic STOCEM lethality against enemy tanks and APCs, with a higher reduction associated with a higher strength advantage (for the attacker).

(b) Investigate methods which enable CEM to simulate a "conservative use" policy for a force's mechanized weapon systems. Such a policy sharply reduces the vulnerability of mechanized systems after a period of heavy losses when favorable attack conditions have been created.

(c) Investigate methods for simulating, for a limited duration, a "breakthrough" combat attack posture which generates significantly accelerated defender attrition and is related to attacker speed and overwhelming attacker force advantage. Modifications to both COSAGE combat samples and CEM should be examined. The large disproportions, over time, in historical US/UK system losses during the Ardennes Campaign indicate that CEM is currently biased in favor of a defender when modeling an attacker executing a catastrophic breakthrough.

(2) Input-driven

(a) Investigate reducing ARCAS input vulnerability of armor and AT/M systems.

(b) Investigate increasing ARCAS input vulnerability of artillery systems.

d. Personnel Casualties

(1) Logic-driven

(a) Investigate methods which reduce an attacking force's basic STOCEM lethality against enemy personnel, with a higher reduction associated with a higher strength advantage (for the attacker).

(b) Investigate adoption of a revised rule for redistributing personnel casualties over the four casualty types (KIA/WIA/ CMIA/DNBI). A new redistribution rule was developed by using the observed differences between historical and STOCEM results to develop a multiplicative adjustment factor for each casualty type. This rule, or, variants of it, should be examined for use in the STOCEM processor logic which partitions personnel casualties.

(c) Investigate methods for simulating a "breakthrough" combat attack posture which generates significantly accelerated defender CMIA and DNBI casualties and which is related to attacker speed and overwhelming attacker force advantage. The initial German breakthrough produced disproportionately large historical US/UK CMIA and DNBI casualties which are not reflected in STOCEM results.

(2) Input-driven. Consideration should be given to reducing ARCAS input personnel vulnerabilities of personnel engaging an attacking force.

Table 7-2. Areas of Investigation for STOCEM Input/Logic Modification

Outcome type	ARCAS STOCEM input modification	STOCEM logic modification
FEBA	Reduce input move rates in attack	(1) Reduce move rate after a sustained advance (2) Stop unit movement at a set objective.
Ammunition expenditure	Revise German single round weight inputs	
Weapon system losses	(1) Reduce vulnerability of armor & AT/M systems (2) Increase vulnerability of artillery (3) Simulate conservation of mechanized systems when strength is sufficient	(1) Reduce lethality of an attacking force (2) Simulate conservation of mechanized systems when strength is sufficient (3) Simulate accelerated attrition during a catastrophic breakthrough
Personnel losses	(1) Reduce vulnerability against an attacking force (2) Change partition of casualties into KIA/WIA/CMIA/DNBI	(1) Reduce lethality of an attacking force (2) Change partition of casualties into KIA/ WIA/CMIA/DNBI (3) Simulate accelerated CMIA and DNBI during a catastrophic breakthrough

7-7. FOLLOW-ON WORK. Follow-on work planned for ARCAS includes:

a. Additional STOCEM Excursions for Hypothesis Testing. Since the inputs and factors producing ARCAS STOCEM results are many and complex, rationales developed from ARCAS results (i.e., differences between STOCEM and history) must be regarded as hypotheses which can gain (or lose) support through additional ARCAS STOCEM excursion cases. Such testing will be done as required and as resources permit.

b. Derivation of Quantified Combat Relationships from the ACSDB. The ACSDB can be used to derive historical statistics which may be used to develop or refine "rules of combat" that could be used to improve current combat models. For example, relationships between casualty ratio and force ratios can be examined. This work will be undertaken as resources permit.

c. Simulation of the Kursk Battle. CAA is in the early stages of an effort with parallel objectives to ARCAS, but which treats the WWII Battle of Kursk. A large data collection effort has been undertaken and is expected to be completed early in 1996. Specific plans for simulating Kursk will be prepared while the final stages of its data collection effort are being completed.

APPENDIX A

STUDY CONTRIBUTORS

A-1. STUDY TEAM

a. Study Director

Mr. Walter J. Bauman, Tactical Analysis Division

b. Team Members

Mr. William T. Allison
Dr. Ralph E. Johnson

c. Contributors

Ms. Julianne Allison
Mr. Greg Andreozzi
Mr. Ronald B. Bonniwell
Dr. Robert L. Helmbold
Mr. Arthur Parker (COL USA, Ret)
Mr. E.B. Vandiver III
Mr. Howard G. Whitley III

A-2. PRODUCT REVIEW BOARD

Mr. Ronald J. Iekel, Chairman

Mr. Gerald E. Cooper

Dr. Robert L. Helmbold

APPENDIX B

STUDY DIRECTIVE

MEMORANDUM FOR: DIRECTOR, U.S. ARMY CONCEPTS ANALYSIS AGENCY
8120 WOODMONT AVENUE, BETHESDA, MD 20814

SUBJECT: Ardennes Campaign Simulation Study Follow-on (ARCAS-FO) Study

1. PURPOSE OF DIRECTIVE. This directive provides for the conduct of a study to compare the Ardennes 1944-45 campaign of World War II (WWII) with the results of a combat simulation of the same campaign, using inputs generated from a history data base describing the campaign.

2. BACKGROUND. In 1987, the Director, U.S. Army Concepts Analysis Agency (CAA), proposed that a WWII campaign be selected for representation by an operational theater combat simulation at CAA. Using historical data as input, the campaign is subsequently recreated, as closely as possible, through simulation. Simulation results can then be compared with history data and can also be used to assess needed changes and/or improvements in rules, algorithms, and capabilities of the combat model employed. In September 1987, the Historical Evaluation and Research Organization (HERO) was issued a contract to construct a comprehensive history data base of the WWII Ardennes 1944-45 campaign (also known as the Battle of the Bulge). This data base, designated as the Ardennes Campaign Simulation Data Base (ACSDB), was completed in December, 1989 by Data Memory Systems, Incorporated. The Ardennes Campaign Simulation (ARCAS) Study was initiated in 1990 to simulate the Ardennes Campaign and compare the results with history reflected in the ACSDB. The combat simulation chosen for the analysis was the Concepts Evaluation Model IX (CEM IX). Only interim and preliminary results were generated in the ARCAS Study due to competing analytic priorities and commitments. The interim ARCAS results indicated a requirement for application of a stochastic combat simulation in ARCAS to supplement the deterministic results from CEM IX. A follow-on effort, the Ardennes Campaign Simulation Follow-on (ARCAS-FO) Study, was created to complete the objectives of the ARCAS Study with a stochastic combat simulation. The stochastic combat simulation chosen for the ARCAS-FO analysis was the Stochastic CEM (STOCEM), a stochastic version of CEM IX.

3. STUDY SPONSOR AND STUDY DIRECTOR. ARCAS-FO is a CAA in-house study. The study sponsor is the Director, U.S. Army Concepts Analysis Agency. The study director is Mr. Walter J. Bauman.

4. PERFORMING AGENCY. U.S. Army Concepts Analysis Agency.

5. PURPOSE. The purpose of the Ardennes campaign Simulation Study is to determine how, where, and why patters of simulated STOCEM combat representing the WWII Ardennes Campaign of 1944-45 are similar to, or differ from, patterns reflected in historical Ardennes Campaign archive (history) recorded in a data base. Similarities between trends in STOCEM outcomes and history can provide support for model validation (of STOCEM/CEM). If a STOCEM trend differs substantively from the historical record, then, if a rationale for that historical outcome/trend can be discerned, justified, and quantified, it can become the basis for modification of STOCEM simulation logic which will improve STOCEM realism and credibility.

6. OBJECTIVES. Use the comparison of STOCEM simulation results with history to:

a. Assess the appropriateness and verisimilitude of simulation algorithms; i.e., whether the trends in the STOCEM combat simulation results are similar to historical results. If so, then the appropriateness of the combat model's underlying logic gains credibility.

b. Discover any needed changes and/or improvements in rules, algorithms, and capabilities of the combat model employed. When combat simulation results and trends differ substantively from history, reasons are sought to explain the difference.

c. Support verification and validation (V&V) of the STOCEM simulation.

7. SCOPE.

a. The base campaign scenario used in the combat simulation is the 1944-45 WWII Ardennes Campaign represented in the ACSDB historical data.

b. The combat simulation used to represent the historical campaign is the STOCEM.

c. Each STOCEM scenario is executed for 16 stochastic replications. Each STOCEM result is represented as an average over the 16 stochastic outcomes.

d. Uncertainty in STOCEM outcomes is statistically expressed in terms of confidence limits and maximum/minimum values over the 16 replications.

e. Campaign outcome measures available for comparison (STOCEM vs history) include personnel casualties, weapon system kills, ammunition consumption, and progress of the forward edge of the battle area (FEBA).

8. TIMEFRAME. The scenario timeframe is from 16 December 1944 (denoted as D-day) through 16 January 1945.

9. LIMITATIONS.

a. STOCEM simulates casualties only in line units and artillery units. Casualties and system kills in nonartillery rear echelon units are excluded from analysis

b. STOCEM reports personnel casualties stratified into casualty types (e.g., KIA, WIA) only for the US/UK force (although total casualties are generated in the same manner for both sides).

c. The 16 replications of STOCEM executions for each scenario are not sufficient to assume that the average STOCEM outcome can be based on a statistically normal sampling distribution of the mean.

d. Comparisons between STOCEM results and historical results can be meaningfully done only for theater averages over large aggregates of units and areas. The STOCEM does not have the resolution to enable comparison of low-level (unit/corps) battle and movement.

e. Human factors (e.g., fatigue, caution, aggressiveness) regulating the pace and intensity of battle were not quantifiable.

10. ASSUMPTIONS.

a. The Ardennes Campaign Simulation Data Base adequately represents the status and structure of forces in the actual WWII Ardennes Campaign of 1944-45.

b. A baseline historical FEBA comparable to the FEBA used in CEM can be defined by averaging locations of unit subelement locations reported in the ACSDB. Location reporting errors in the ACSDB are assumed negligible.

c. Weapon effectiveness inputs were based to the maximum extent possible on data from system and munition types employed in WWII. When lethality data on WWII munitions were unavailable, required effectiveness measures were based on comparable postwar surrogate munitions for which data were available.

d. The personnel casualty and system kill criteria used to categorize CEM results are consistent with and comparable to the casualty/kill criteria reflected in the historical data, enabling direct comparison of STOCEM casualties/kills with historic casualties/kills.

11. ESSENTIAL ELEMENTS OF ANALYSIS (EEA).

a. What major similarities and differences in critical elements exist between the ARCAS STOCEM results of the Ardennes Campaign and the historical record of that battle?

b. What appear to be the causes of the differences between simulation results and those from the historical battle records?

c. What implications on the validity of the STOCEM theater combat simulation process can be derived from the comparison of ARCAS STOCEM results with those from history?

d. What changes in STOCEM, the kind of inputs it uses, or the way the model is applied are suggested by this comparison as appropriate for future simulations?

12. RESPONSIBILITIES. Since this is an internal study, CAA will direct the study, obtain the necessary data, perform model runs and analysis, compare results with history, and document the study. Specific responsibilities are as detailed in the ARCAS Study Plan.

13. LITERATURE SEARCH. Related studies and documents include:

a. Cole, Hugh M., the Ardennes: Battle of the Bulge, United States Army in World War II, The European Theater of Operations, Washington, D.C.; United States Government Printing Office, 1965

b. Eisenhower, John S. D., The Bitter Woods, G.P. Putnam's Sons, 1969.

c. MacDonald, Charles B., A Time for Trumpets: The Untold Story of the Battle of the Bulge, William Morrow and Company, Inc., 1985.

14. REFERENCES.

a. Ardennes Campaign Simulation Data Base (ACSDB) Statement of Work, RFP No. MDA903-87-R-0091, CAA, CSCA-FO

b. Ardennes Campaign Simulation Data Base (ACSDB) User's Guide, 18 December 1989, Data Memory Systems, Inc., Contract no. MDA903-87-C-0787

c. Concepts Evaluation Model VII (CEM IX), Volume I - Technical Description, August 1985 (revised October 1987), US Army Concepts Analysis Agency

d. Concepts Evaluation Model VII (CEM IX), Volume II - User's Handbook, August 1985 (revised December 1991), US Army Concepts Analysis Agency

e. Single-Shot Probability of Kill (SSPK) and Related Weapons Data for the Ardennes Campaign Simulation Data Base (ACSDB), 29 December 1989, Data Memory Systems, Inc., Contract no. MDA903-87-C-0787

f. The Ardennes Campaign Simulation Data Base (ACSDB), Phase II Final Report (deliverable 0002AK), 7 Feb 90, Data Memory Systems, Inc., Vol I of II and Vol II of II, Contract no. MDA903-87-C-0787

15. ADMINISTRATION.

a. Initial meeting with sponsor was held in February 1994.

b. Interim progress reviews will be conducted in December 1994 and May 1995.

c. Briefing of final results is planned for December 1995. Basic final results will be briefed at the Special Conference on Historical Data Analysis (SCOHDA) in July 1995.

d. CAA point of contact is Mr. Walter J. Bauman, CSCA-TA, DSN 295-5261 or commercial (301) 295-5261.

e. This memorandum complies with the missions, functions, and procedures of the U.S. Army Concepts analysis Agency.

E. B. Vandiver III
Director

APPENDIX C

REFERENCES/BIBLIOGRAPHY

REFERENCES

1. AR 5-11, Army Model and Simulation Management Program, Department of the Army, 1992

2. Ardennes Campaign Simulation Data Base (ACSDB) User's Guide, Data Memory Systems, Inc., Contract no. MDA903-87-C-0787, 18 December 1989

3. The Ardennes Campaign Simulation Data Base (ACSDB), Phase II Final Report (deliverable 0002AK, Data Memory Systems Inc., Vol. I of II and Vol. II of II, Contract no. MDA903-87-C-0787) 7 February 1990

4. Stochastic Concepts Evaluation Model (STOCEM), CAA-TP-91-6, US Army Concepts Analysis Agency, August 1991

5. Concepts Evaluation Model VII (CEM VII), Volume I - Technical Description, US Army Concepts Analysis Agency, August 1985 (revised October 1987)

6. Concepts Evaluation Model VII (CEM VII), Volume II - User's Handbook, US Army Concepts Analysis Agency, August 1985 (revised December 1991)

7. Salvatore, Dominic, Schaum's Outline of Theory and Problems of Statistics and Econometrics, Schaum's Outline Series, McGraw-Hill, Inc., 1982

8. Cockrell, James K., Carter, Donn, Research Study on Predictive War Game Factors, Final Report, RMC Research Corporation, March 1974

9. Goad, R., Predictive Equations for Opposed Movement and Casualty Rates for Land Forces, paper published in Military Strategy and Tactics, Computer Modeling and Land Warfare Problems, New York, Plenum Press, 1975

10. Dupuy, Trevor N., Bongard, David L., Anderson, Richard C. Jr., Hitler's Last Gamble, Harper Collins Publishers 1994

11. Parker, Danny S., Battle of the Bulge, Hitler's Ardennes Offensive, 1944-45, Combined Books, 1991

BIBLIOGRAPHY

Arnold, James R., ARDENNES 1944, Hitler's Last Gamble in the West, Campaign Series, Osprey Publishing, 1990

Cirillo, Roger, ARDENNES-ALSACE, The US Army Campaigns of World War II, US Army Center of Military History, CMH Pub 72-26, 1993+

Cole, Hugh M., The Ardennes: Battle of the Bulge, United States Army in World War II, The European Theater of Operations, Washington, DC; United States Government Printing Office, 1965

COSAGE User's Manual, Volume I - Main Report, US Army Concepts Analysis Agency, April 1993 (revised August 1995)

COSAGE User's Manual, Volume II - Input/Output Guide, US Army Concepts Analysis Agency, April 1993 (revised August 1995)

Dworschak, Thomas W., Hitler's "Watch on the Rhine," the Battle of the Bulge, The Land Warfare Papers No. 12, The Institute of Land Warfare, Association of the United States Army, 1992

Eisenhower, John S. D., The Bitter Woods, G.P. Putnam's Sons, 1969

Goldstein, Donald M., Katherine Dillon, J. Michael Wenger, Nuts! The Battle of the Bulge, Brassey's, 1994

MacDonald, Charles B., A Time for Trumpets: The Untold Story of the Battle of the Bulge, William Morrow and Company, Inc., 1985.

Pimlott, John, Battle of the Bulge, Bison Books, Ltd., 1981

APPENDIX D

FORCE COMPOSITION AND STRENGTH DATA

D-1. OVERVIEW. This appendix supplements and amplifies Chapter 2 of the report. The types of weapons simulated in STOCEM are listed, along with their associated weapon class in STOCEM. Tables show the unit strengths, extracted from the ACSDB, which were used as initial input conditions for the STOCEM ARCAS scenario. The number of weapons, by STOCEM weapon class, and the number of personnel in each simulated line unit at the time of its availability for commitment are listed. Number and types of daily aircraft sorties in the historical campaign are also charted. These data were extracted from the ACSDB and were the basis for STOCEM inputs. For completeness, line units in the ACSDB which were not used in the ARCAS scenario are also listed, along with the chief reasons for their nonselection.

D-2. TYPES OF WEAPON SYSTEMS. The types of weapon systems used in the ARCAS STOCEM simulation are shown in Tables D-1 (US/UK force) and D-2 (German force). The systems are grouped according to their associated weapon class in STOCEM. The names of the weapon system types are those used in the ACSDB. UK weapon systems are prefixed by (UK).

Table D-1. ARCAS US/UK Weapon Systems

Tanks	APCs
(UK) Churchill tank	(UK) BSA Daimler scout car
(UK) Cromwell tank	(UK) Humber scout car
(UK) Sherman tank(Firefly)	(UK) Morris reconaissance car
M-10 tank destroyer	(UK) Daimler armored car
M-18 tank destroyer (Hellcat)	(UK) BSA Daimler scout car
M-36 tank destroyer (Jackson)	(UK) Humber scout car
M-5A1 light tank (Stuart)	M-3 half-track
M-4 tank (Sherman)	M-8 armored car
	M-20 armored utility vehicle

AT/Mortars	Artillery
(UK) 2" mortar	(UK) Churchill 95mm howitzer
(UK) 3" mortar	(UK) Cromwell 95mm howitzer
(UK) 4.2" mortar	(UK) 25-pounder howitzer
M-2 60mm mortar	(UK) 5.5" gun-howitzer
M-1 81mm mortar	(UK) 7.2" howitzer
M-1 4.2" mortar	M-1 75mm howitzer
M-21 81mm mortar	M-8 75mm howitzer
(UK) 6-pounder antitank gun	M-2A1 105mm howitzer
(UK) 17-pounder antitank gun	M-3 105mm howitzer
M-3A1 37mm antitank gun	M-7 105mm howitzer
M-1 57mm antitank gun	M-1 4.5" gun
M-5 3" antitank gun	M-1A1 155mm gun
	M-12 155mm gun
	M-1 155mm howitzer
	M-1 8" howitzer
	M-1 240mm howitzer
	M-4 tank w/ 105mm howitzer

Table D-2. ARCAS German Weapon Systems

Tanks	APCs
HIG SIG 33 heavy gun	SdKfz 250 half-track
Brumbaer 150mm heavy gun	SdKfz 251 half-track
105mm assault gun	Armored cars w/20mm gun
Mark IV tank	Armored cars w/50mm or 75mm gun
Mark V tank (Panther)	
Mark VIe tank (Tiger I, Tiger II)	

AT/Mortars	Artillery
GrW 34 80mm mortar	75mm gun
GrW 42 120mm mortar	75 mm howitzer
Pak 38 50mm antitank gun	88mm gun
Pak 40 75mm antitank gun	Kan 18 105mm gun
Pak 43/41 88mm antitank gun	152mm gun
75mm antitank gun	105mm howitzer
75mm assault gun	122mm howitzer
88mm antitank gun	150mm howitzer
	170mm gun
	210mm howitzer
	355mm howitzer
	240mm railway gun
	280mm railway gun
	Nebelwerfer 41 150mm rocket launcher
	Nebelwerfer 42 210mm rocket launcher
	Nebelwerfer 42 280mm rocket launcher

D-3. WEAPON SYSTEMS IN UNITS AVAILABLE FOR COMMITMENT. Tables D-3 and D-4 show the number of onhand land force weapon systems, by STOCEM weapon class, in each simulated ARCAS line unit at the time of that unit's initial availability for commitment in the ARCAS scenario. Table 2-2 of the main report gives the time-phasing of unit availability for commitment. Table D-3 shows weapon strength in US/UK units, while Table D-4 describes German units. These unit strengths were extracted from the ACSDB.

Table D-3. Initial Onhand Weapon System Strength in US/UK Units

Unit	Tanks	APCs	AT/Mortars	Arty tubes
2d AD	427	1,031	214	136
3d AD	345	862	154	132
4th AD	186	521	100	87
6th AD	264	614	114	148
7th AD	253	556	111	90
9th AD	261	555	111	89
10th AD	242	550	111	88
11th AD	215	549	107	89
17th AbnD	4	32	179	70
82d AbnD	12	20	140	68
101st AbnD	12	14	140	93
1st ID	133	83	214	72
2d ID	51	91	255	104
4th ID	57	103	245	96
5th ID	81	75	237	70
26th ID	97	107	235	102
28th ID	47	107	247	80
30th ID	79	99	287	72
35th ID	31	48	213	78
75th ID	97	60	221	72
80th ID	88	93	234	67
83d ID	55	63	222	71
84th ID	103	64	210	71
87th ID	17	18	201	66
90th ID	85	58	208	72
99th ID	32	58	223	85
106th ID	30	206	269	84
29th ArmBde(UK)	119	99	79	52
51st ID (UK)	0	78	380	72
53d ID (UK)	0	79	383	72
Total	**3,304**	**6,893**	**6,044**	**2,548**

Table D-4. Initial Onhand Weapon System Strength in German Units

Unit	Tanks	APCs	AT/Mortars	Arty tubes/ launchers
1st SSPzD	99	151	122	163
2d SSPzD	93	244	173	88
9th SSPzD	80	185	168	88
12th SSPzD	83	157	176	179
PzLehrD	56	142	114	102
2d PzD	84	164	143	84
9th PzD	64	141	91	50
116th PzD	54	141	106	47
9th VGD	6	0	141	109
12th VGD	6	0	80	76
18th VGD	8	0	100	100
26th VGD	0	0	98	120
62d VGD	6	0	84	91
79th VGD	18	0	77	76
167th VGD	5	0	69	81
212th VGD	6	0	115	91
276th VGD	5	0	59	83
277th VGD	5	0	69	83
340th VGD	5	0	70	83
352d VGD	6	0	80	99
560th VGD	6	0	74	91
3d PzGD	7	75	129	46
15th PzGD	17	28	118	49
3d FJD	0	0	103	25
5th FJD	7	0	229	89
150th PzBde	0	54	33	0
FBB	43	75	76	21
FGB	56	131	110	57
Total	**825**	**1,688**	**3,007**	**2,271**

D-4. PERSONNEL STRENGTH IN UNITS AVAILABLE FOR COMMITMENT. Tables D-5 and D-6 show the number of onhand personnel, by STOCEM weapon class, in each simulated ARCAS line unit at the time of that unit's initial availability for commitment. Although only infantry and artillery personnel are explicitly simulated in STOCEM, personnel are shown in three categories: infantry personnel, artillery personnel, and all personnel (which includes those in the previous two categories). Table D-5 shows personnel strength US/UK units, while Table D-6 describes German units. These unit strengths were extracted from the ACSDB.

Table D-5. Initial Onhand Personnel Strength in US/UK Units

Unit	Infantry	Artillery	All personnel
2d AD	2291	3116	18343
3d AD	2194	2709	15783
4th AD	2583	1646	11283
6th AD	3106	3621	14008
7th AD	2997	1662	11950
9th AD	3039	1663	12001
10th AD	2462	1641	10971
11th AD	2825	1657	11483
17th AbnD	8707	2287	13506
82d AbnD	7569	2548	12244
101st AbnD	10139	3961	15973
1st ID	8743	2142	16468
2d ID	8809	4243	17028
4th ID	8549	3882	17473
5th ID	9320	2661	16341
26th ID	9965	3538	18467
28th ID	9670	3339	16649
30th ID	11890	3125	18934
35th ID	9676	2818	16162
75th ID	9407	2325	16542
80th ID	9543	2724	16623
83d ID	8517	2670	14796
84th ID	8503	3183	17599
87th ID	7530	2101	12499
90th ID	9388	2180	15870
99th ID	9202	4069	16467
106th ID	9495	2438	18747
(UK) 29th ArmBde	464	1684	3523
(UK) 51st ID	12395	2892	18309
(UK)53d ID	11851	2766	17506
Total	**220,829**	**81,291**	**453,548**

Table D-6. Initial Onhand Personnel Strength in German Units

Unit	Infantry	Artillery	All personnel
1st SSPzD	7388	3427	21044
2d SSPzD	7203	1884	16982
9th SSPzD	5582	1368	13321
12th SSPzD	8100	3490	20635
PzLehrD	4223	2404	14873
2d PzD	4447	2481	14457
9th PzD	4713	1353	13063
116th PzD	5171	1734	15468
9th VGD	4601	2257	11384
12th VGD	5402	1906	9517
18th VGD	6104	3134	12117
26th VGD	5850	2531	10580
62d VGD	6753	2000	11050
79th VGD	6192	1928	10106
167th VGD	6450	1986	10681
212th VGD	6303	2630	11151
276th VGD	5362	1903	9320
277th VGD	3579	1779	7249
340th VGD	3790	1794	7517
352d VGD	6387	1975	10595
560th VGD	6753	2000	11197
3d PzGD	5012	1327	11532
15th PzGD	5255	1183	11189
3d FJD	6848	1803	12927
5th FJD	9333	2669	16342
150th PzBde	1850	400	2955
FBB	2838	473	6827
FGB	2649	2033	6241
Total	**154,138**	**55,852**	**330,320**

D-5. AIR SORTIES. Table D-7 shows types of US/UK aircraft, according to role (ground attack/air-to-air) which supported the overall Ardennes Campaign. Table D-8 shows analogous data for the German force. Figure D-1 shows the total daily air-to-ground sorties recorded in the ACSDB for the ground attack aircraft types listed in Table D-7. Figure D-2 shows the total daily air-to-air sorties recorded in the ACSDB for the air-to-air aircraft types listed in Table D-8.

Table D-7. US/UK Aircraft Types in Each Role

Ground attack	Air-to-air
P-38	P-38
P-47	P-47
A-20	P-51
A-26	P-61
B-17	P-61A
B-24	Typhoon
B-25	Spitfire
B-26	
Mosquito	
Typhoon	
Halifax	
Boston	
Lancaster	
Mitchell	
Tempest	

Table D-8. German Aircraft Types in Each Role

Ground attack	Air-to-air
Ar-234	Fw-190
Fw-190	Fw-190D
Fw-190D	Me-109
Me-262	Me-262
Me-109	

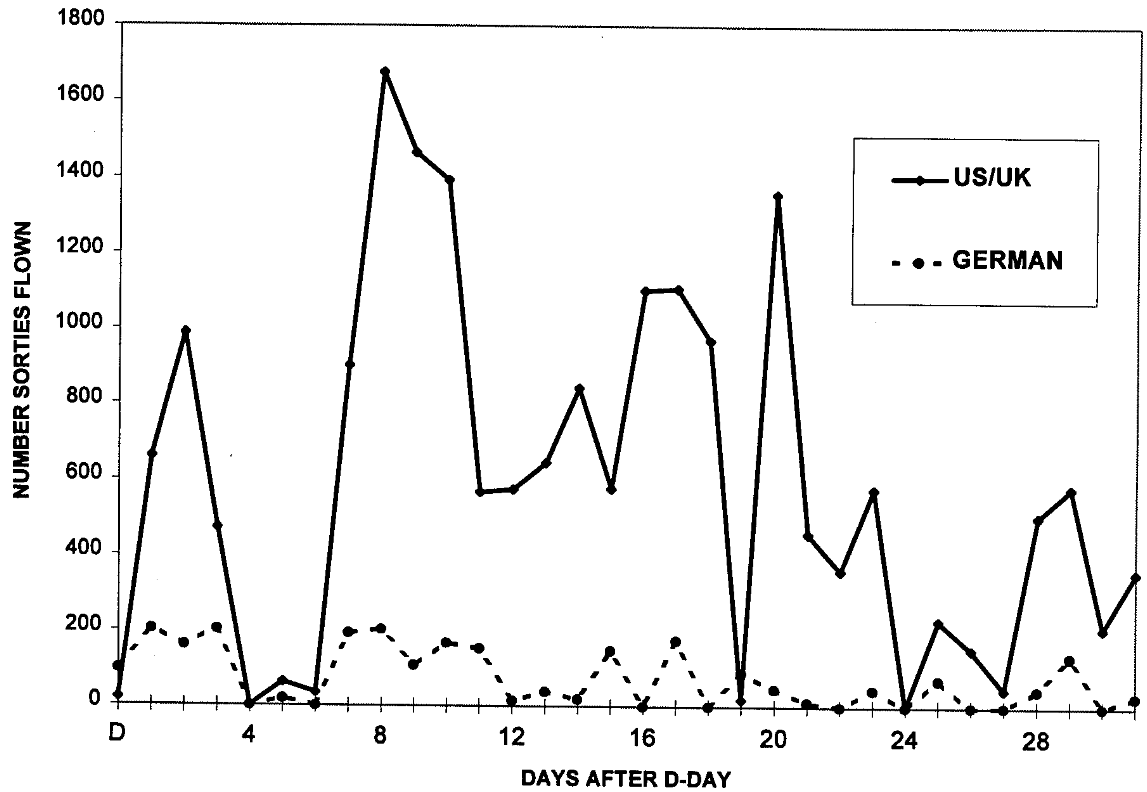


Figure D-1. Air-to-ground Sorties Supporting Overall Ardennes Campaign

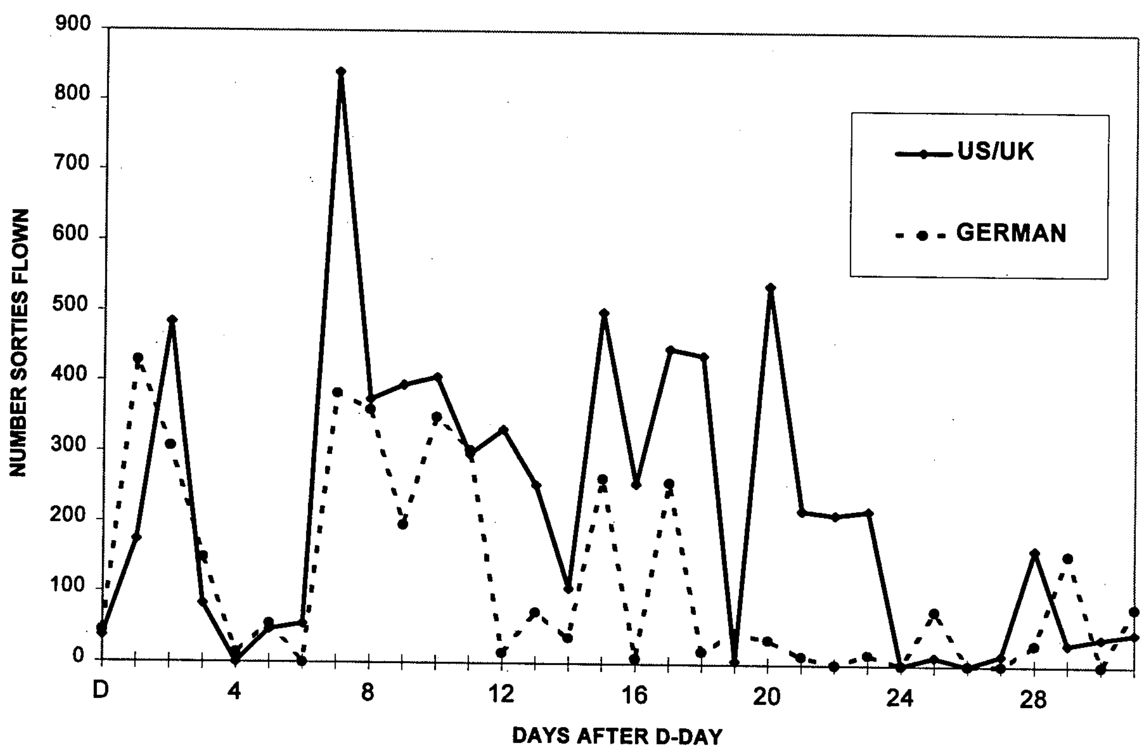


Figure D-2. Air-to-air Sorties Supporting Overall Ardennes Campaign

D-7. UNITS NOT SIMULATED. Chapter 2 of the report stated that the ACSDB included a larger area and more units than are used in the ARCAS scenario. Those line units in the ACSDB which were not used in the ARCAS scenario are listed in Table D-9 (US/UK force) and Table D-10 (German force), along with a brief description of the main reasons for exclusion from the ARCAS scenario.

Table D-9. ACSDB US/UK Line Units Not Simulated in ARCAS

US/UK unit	Main reason for exclusion
5th AD	Operations are north of ARCAS theater
8th ID	Operations are north of ARCAS theater
9th ID	Operations are north of ARCAS theater
29th ID	Operations are north of ARCAS theater
78th ID	Operations are north of ARCAS theater
94th ID	No recorded combat in ACSDB
102d ID	Operations are north of ARCAS theater
104th ID	Operations are north of ARCAS theater
(UK) 33d Arm Bde	No recorded combat in ACSDB
(UK) 34th Tank Bde	No recorded combat in ACSDB
(UK) Guards AD	No recorded combat in ACSDB
(UK) 6th AbnD	No recorded combat in ACSDB
(UK) 43d ID	No recorded combat in ACSDB

Table D-10. ACSDB German Line Units Not Simulated in ARCAS

German unit	Main reason for exclusion
10th SSPzD	No recorded combat in ACSDB
27th SSPzD	No recorded combat in ACSDB
28th SSPzD	No recorded combat in ACSDB
11th PzD	No recorded combat in ACSDB
59th ID	Operations are north of ARCAS theater
85th ID	Operations are north of ARCAS theater
89th ID	Operations are north of ARCAS theater
353d ID	Operations are north of ARCAS theater
272d VGD	Operations are north of ARCAS theater
47th VGD	Operations are north of ARCAS theater
246th VGD	Operations are north of ARCAS theater
326th VGD	Operations are north of ARCAS theater
344th ID	Operations are north of ARCAS theater
363d VGD	Operations are north of ARCAS theater

APPENDIX E

UNCERTAINTY IN HISTORY FEBA POSITIONS

E-1. INTRODUCTION. Chapter 2 (paragraph 2-8) of the report described a methodology for quantifying the spread of uncertainty in the definition of the historical FEBA derived from the ACSDB. Figure 3-4 of the report graphically portrays this uncertainty range at D+8 in the scenario. Figures E-1 through E-8 in this appendix illustrate the effect of uncertainty in the historical FEBA, as quantified in paragraph 2-8, at 4-day intervals throughout the scenario. (Figure 3-2 is identical to Figure 3-8 in the report.) From Chapter 2, the plotted lines in each figure in this appendix are defined as follows:

a. The Base History FEBA is defined as the (line connecting the) average ACSDB location of the westernmost 40 percent of the German ACSDB unit location points on (i.e., closest to) each STOCEM avenue of advance. The Base History FEBA is used as the best estimate of the historical FEBA.

b. The Hi History FEBA is defined as the (line connecting the) single westernmost German ACSDB location point on (i.e., closest to) each STOCEM avenue of advance. This Hi History FEBA is used as an estimator of the upper bound (maximum advance) of the History FEBA.

c. The Lo History FEBA is defined as the (line connecting the) average ACSDB location of all of the German ACSDB location points on (i.e., closest to) each STOCEM avenue of advance. This Lo History FEBA is used as an estimator of the lower bound (minimum advance) of the History FEBA.

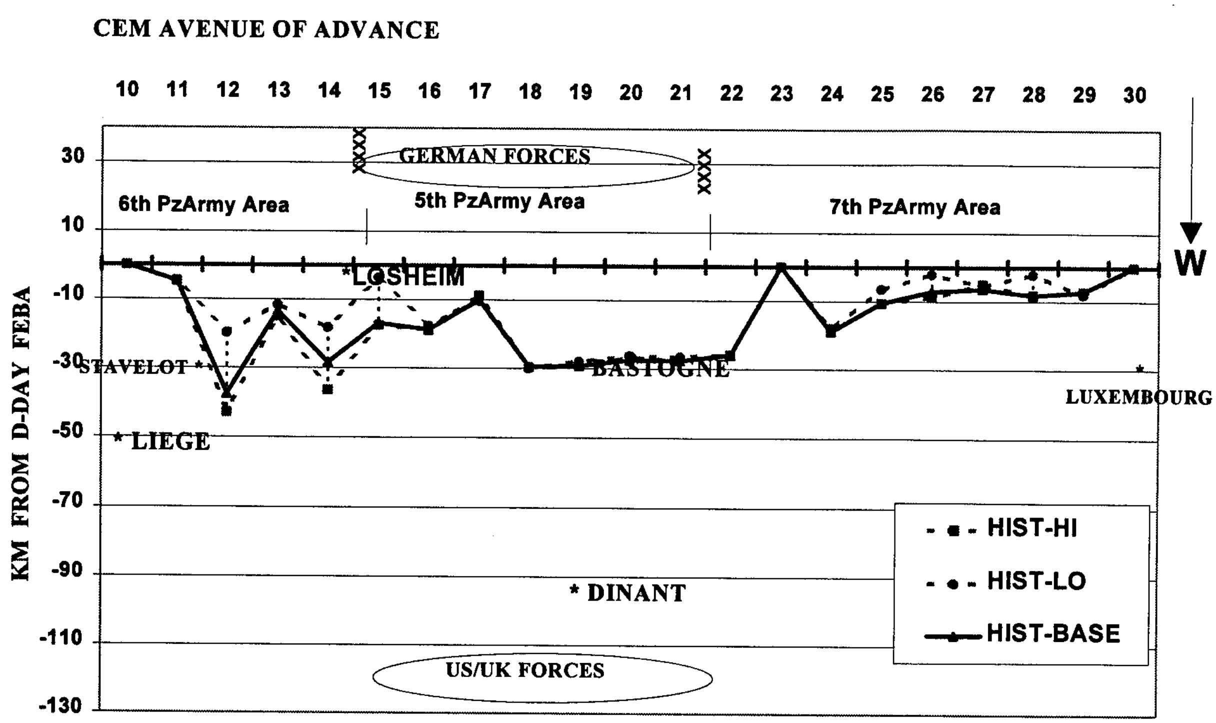


Figure E-1. Uncertainty in Historical FEBA Positions at D+4

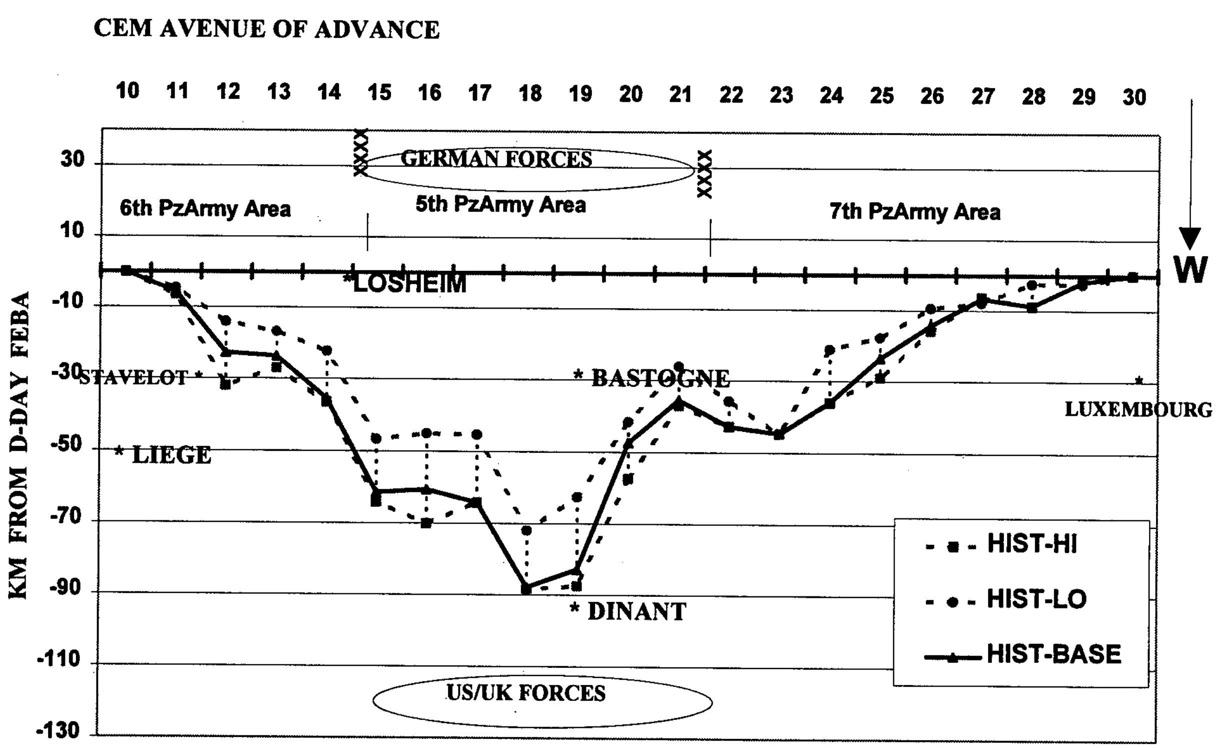


Figure E-2. Uncertainty in Historical FEBA Positions at D+8

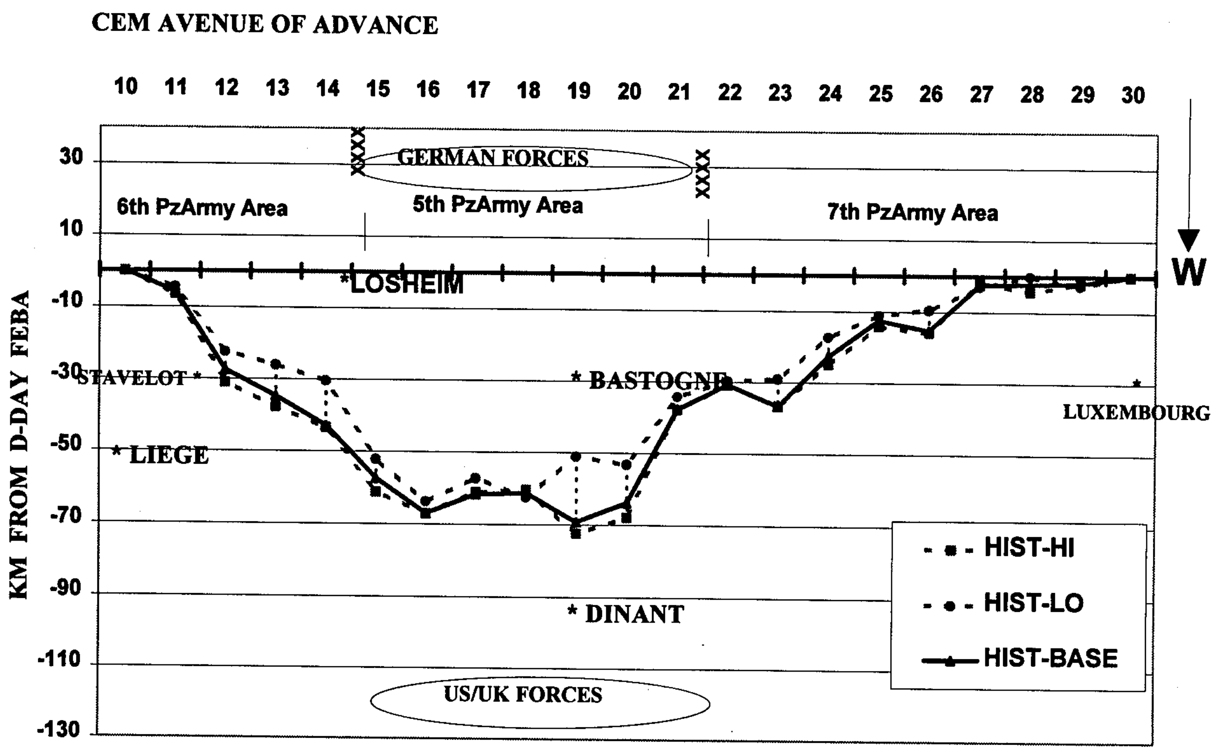


Figure E-3. Uncertainty in Historical FEBA Positions at D+12

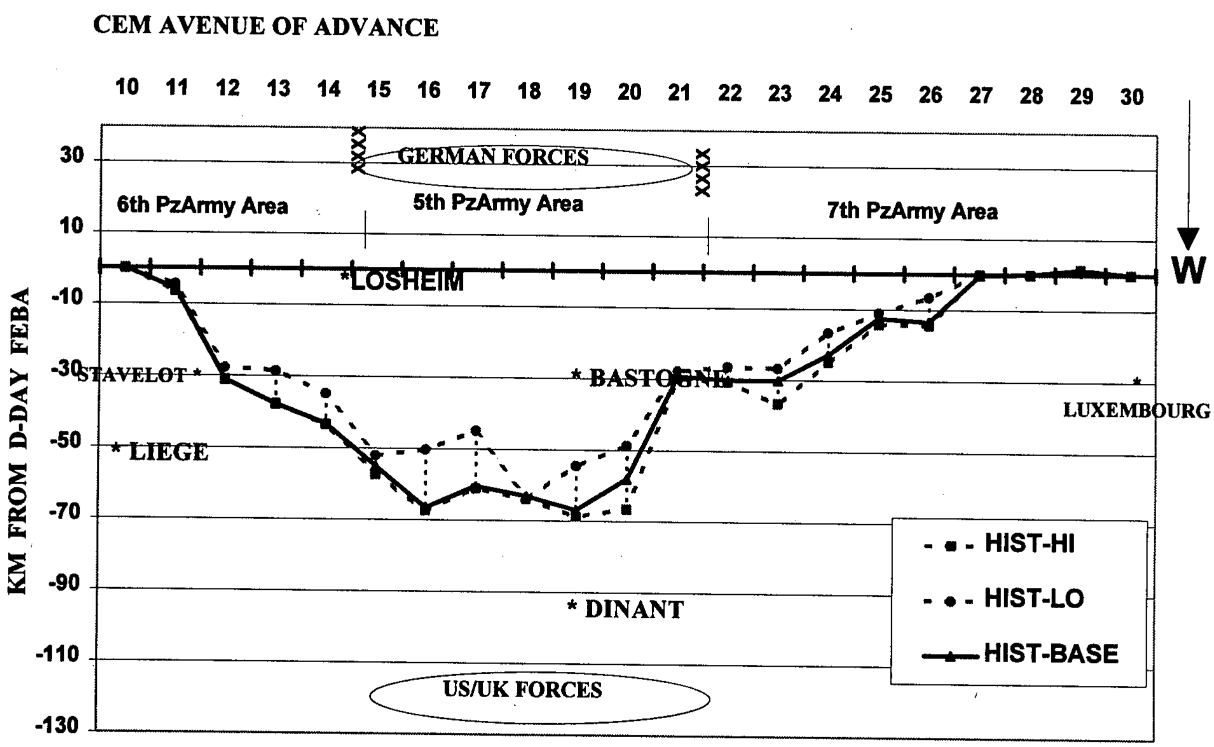


Figure E-4. Uncertainty in Historical FEBA Positions at D+16

CEM AVENUE OF ADVANCE

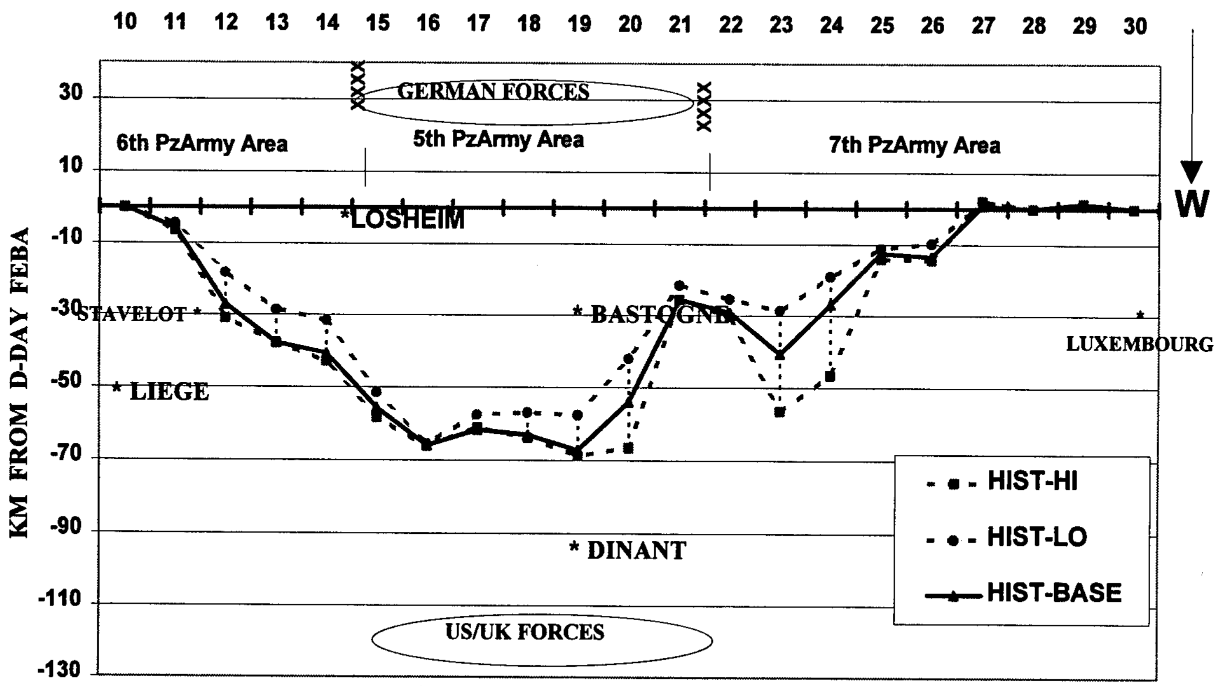


Figure E-5. Uncertainty in Historical FEBA Positions at D+20

CEM AVENUE OF ADVANCE

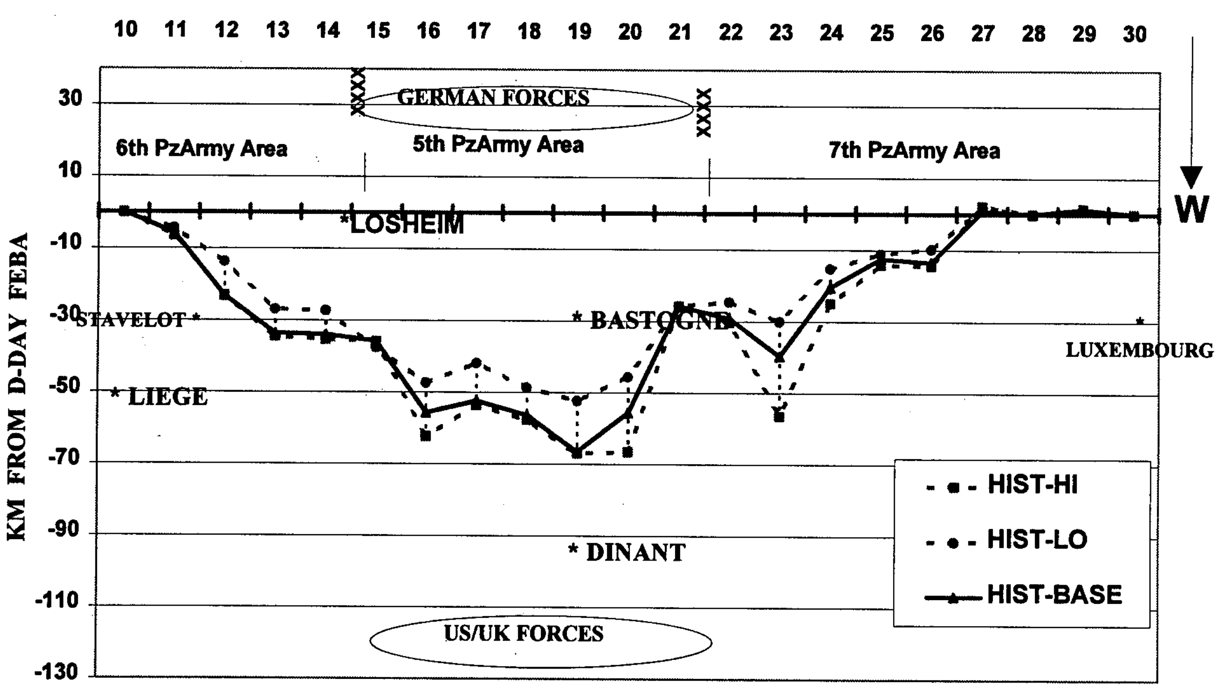


Figure E-6. Uncertainty in Historical FEBA Positions at D+24

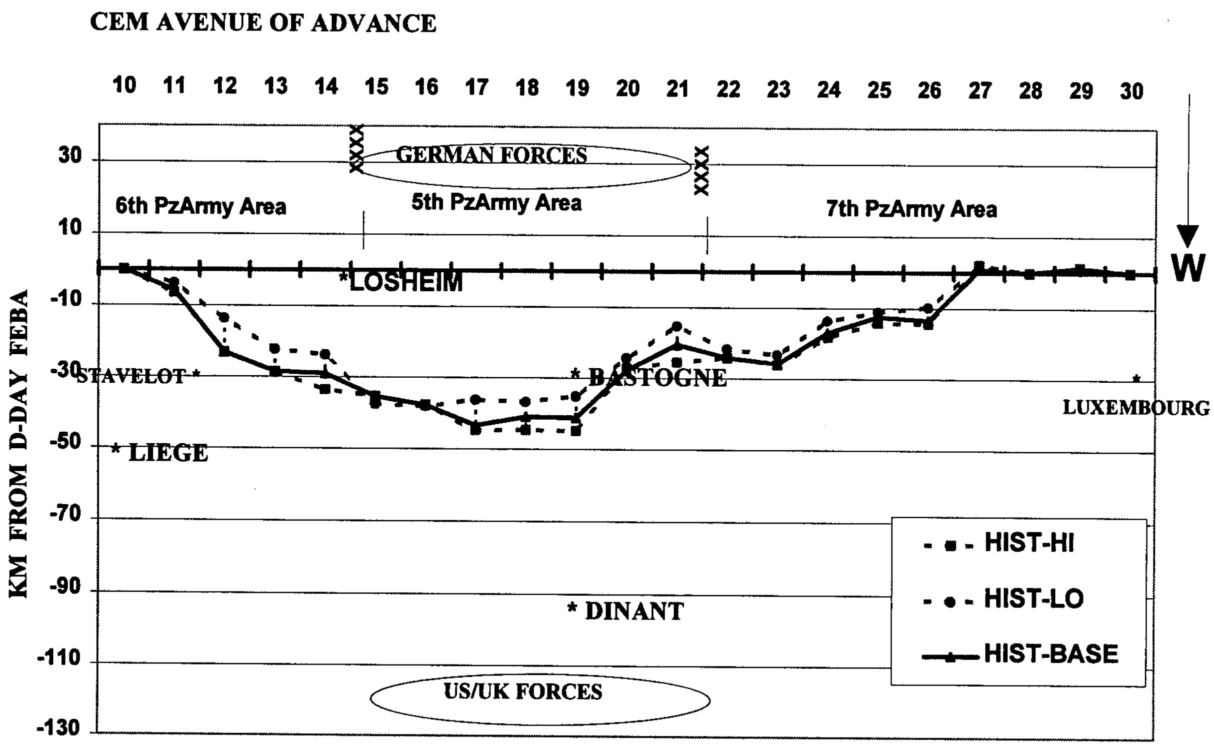


Figure E-7. Uncertainty in Historical FEBA Positions at D+28

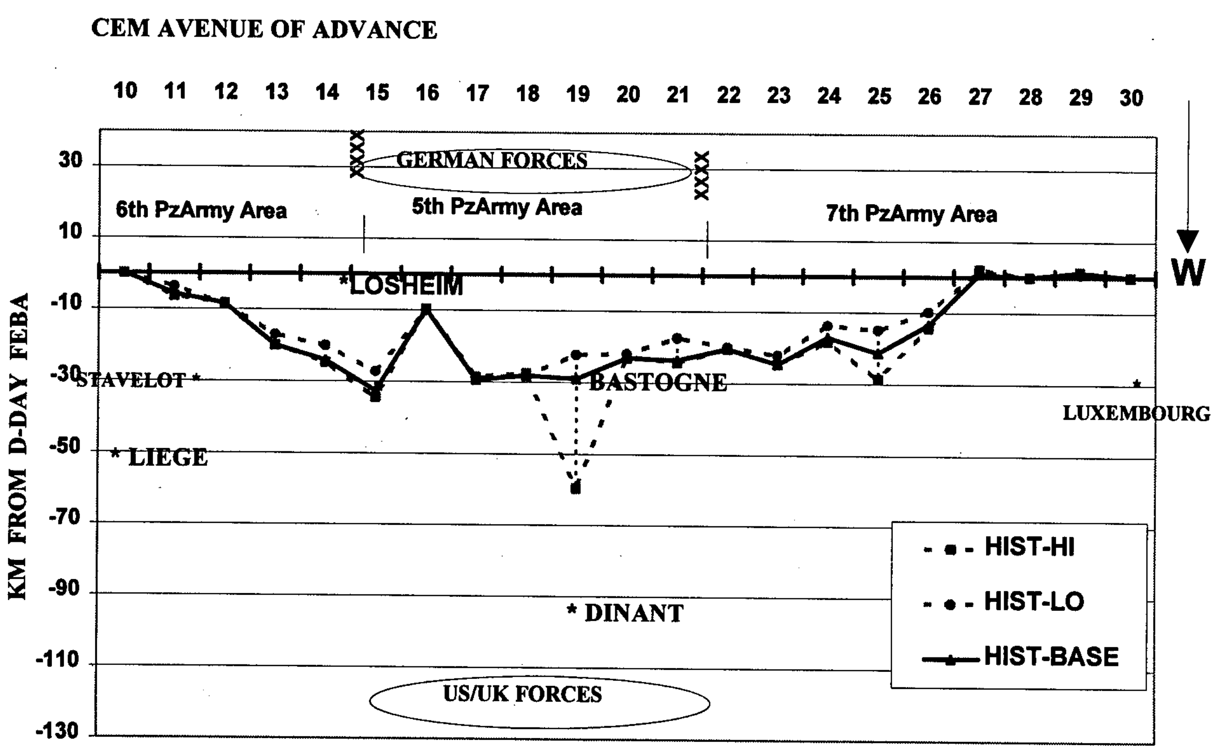


Figure E-8. Uncertainty in Historical FEBA Positions at D+32

APPENDIX F

COMPARATIVE FEBA RESULTS

F-1. OVERVIEW. This appendix supplements and amplifies Chapter 3 of the report. Figures portray and compare the simulation and historical movement of the FEBA during the course of the Ardennes Campaign. The figures depict STOCEM and historical FEBA progress at 4-day intervals during the campaign. Measures of stochastic uncertainty in STOCEM results, based on statistical sampling theory, are also shown on most charts. The first group of figures shows comparative (History vs STOCEM) FEBA results for the STOCEM base case scenario, which is closest to the historical campaign. The second group of figures shows comparative (History vs STOCEM) FEBA results for the STOCEM excursion case scenario, which differed from the STOCEM base case in that it allowed STOCEM to assign reinforcements anywhere in the theater (whereas the STOCEM base case limited them to their historically supported area of operations). The third group of figures compares historical FEBA progress with both the STOCEM base case FEBA progress and the STOCEM excursion case FEBA progress. The last group of figures shows average FEBA progress over time for the STOCEM base case.

F-2. CHART FORMAT AND STRUCTURE. The format of Figures F-1 through F-24 is the same as used in Figure 3-9. Each figure portrays FEBA progress in the theater at a specific day of the campaign. The Base History FEBA for that day, as explained in paragraph 2-8, is defined as the (line connecting the) average ACSDB location of the westernmost 40 percent of the German ACSDB unit location points on (i.e., closest to) each STOCEM avenue of advance. The Base History FEBA represents the progress of the historical FEBA. The Base History FEBA and the average STOCEM FEBA progress are plotted for each of the 21 STOCEM avenues of advance, which are indexed left to right (on the chart) in north to south order. This corresponds to a aerial view looking eastward. The magnitude of the FEBA progress is plotted along each avenue of advance for the specified day of the campaign. The D-day position is at the 0 ordinate, and a negative "km from D-day FEBA" corresponds to a German advance. The components of each figure are as follows:

a. The bars in each figure show, for the day of the campaign associated with the figure:

(1) The average "km from D-day FEBA" STOCEM positions for each CEM avenue of advance. The CEM mean (average) FEBA on a day denotes the average position of the STOCEM FEBA over all 16 replications of STOCEM.

(2) The Base History FEBA position on each CEM avenue of advance in the theater, where the Base History FEBA is defined as above.

b. The dashed line showing the STOCEM maximum FEBA represents the maximum westward advance of the STOCEM FEBA on that day over all 16 replications of the base case. This was computed by finding the westernmost FEBA position, over the 16 replications, on each STOCEM avenue of advance and connecting these avenue maximum FEBA positions. Only one point is plotted in the figure for each measure on each avenue of advance. The lines connecting these points are added only to facilitate visual comparison.

c. The dashed line showing the STOCEM minimum FEBA represents the easternmost position of the STOCEM FEBA on that day over all 16 replications of the base case. This was computed by finding the easternmost FEBA position, over the 16 replications, on each STOCEM avenue of advance and subsequently connecting these avenue minimum FEBA positions.

d. The thin solid line graphs in the figures show the 99 percent/90 percent confidence limits for the average STOCEM FEBA. (These are 99 percent limits under a Normality assumption, but are a 90 percent limit if normality is not assumed.) These are denoted as +3.2 SE and -3.2 SE in the chart because, statistically, they are separated from the STOCEM average by 3.2 standard errors. These two pairs of lines form bands which graphically portray the uncertainty in stochastic variation in the STOCEM FEBA.

This linearized representation emulates a quasi-geography for the battle with the (north-south ordered) STOCEM avenues of advance represented as parallel straight lines. The orientation is from an aerial perspective facing east from above US/UK lines.

F-3. STOCEM BASE CASE FEBA RESULTS. Figures F-1 though F-8 compare the Base History FEBA with the STOCEM base case FEBA in a Cartesian (x-,y-) theater representation at 4-day intervals throughout the campaign. For STOCEM, the measures of simulation uncertainty defined in Chapter 2 are shown, along with the average FEBA progress. For the historical results, only the Base History FEBA is shown.

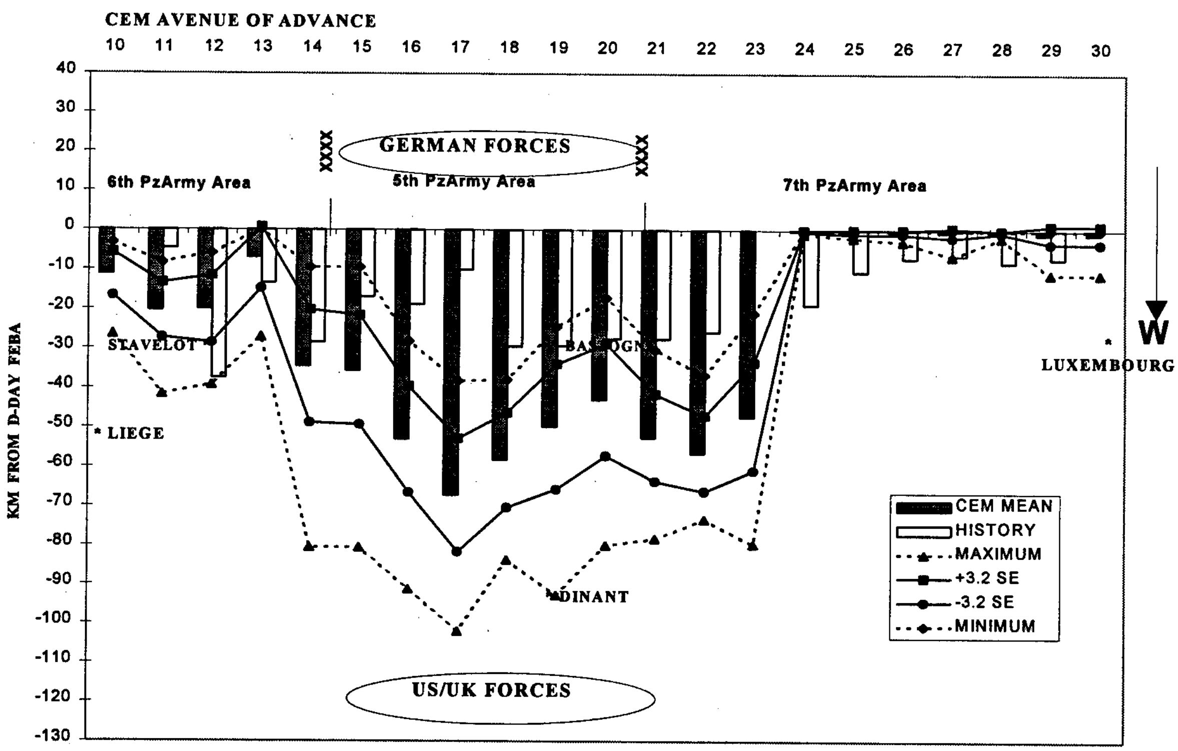


Figure F-1. STOCEM Base Case FEBA vs History on D+4 (with uncertainty)

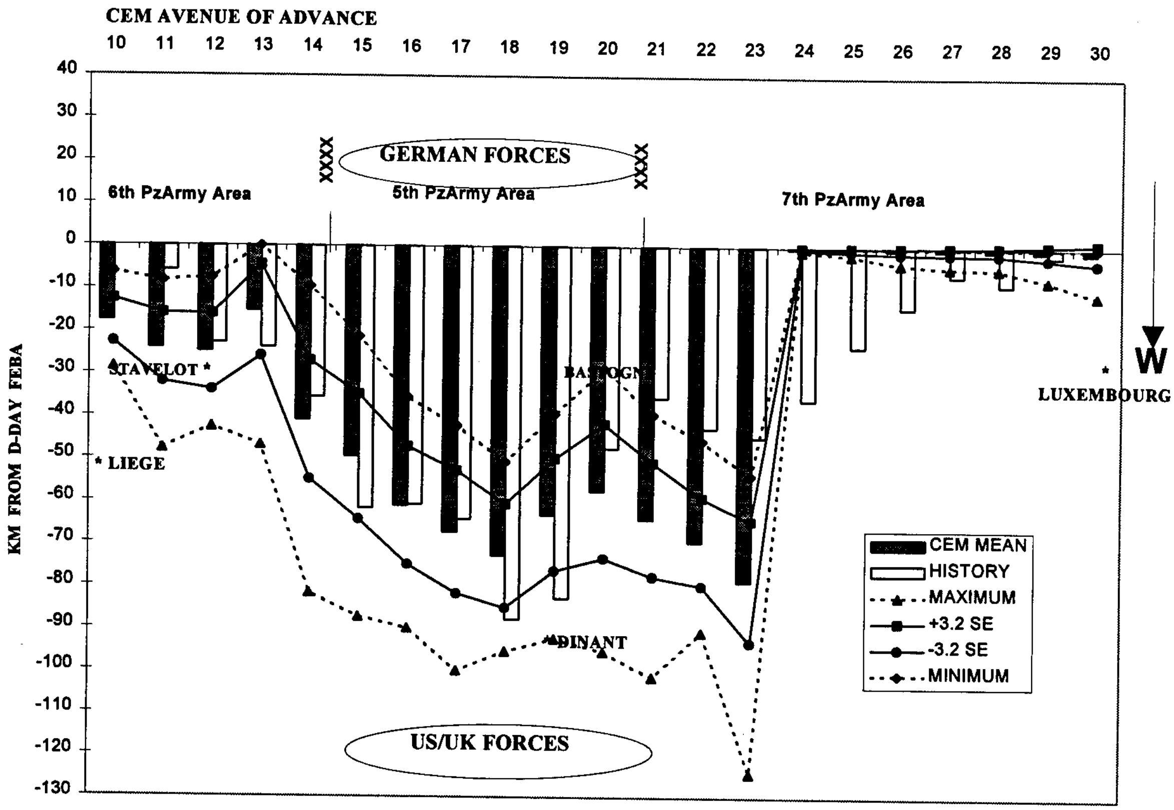


Figure F-2. STOCEM Base Case FEBA vs History on D+8 (with uncertainty)

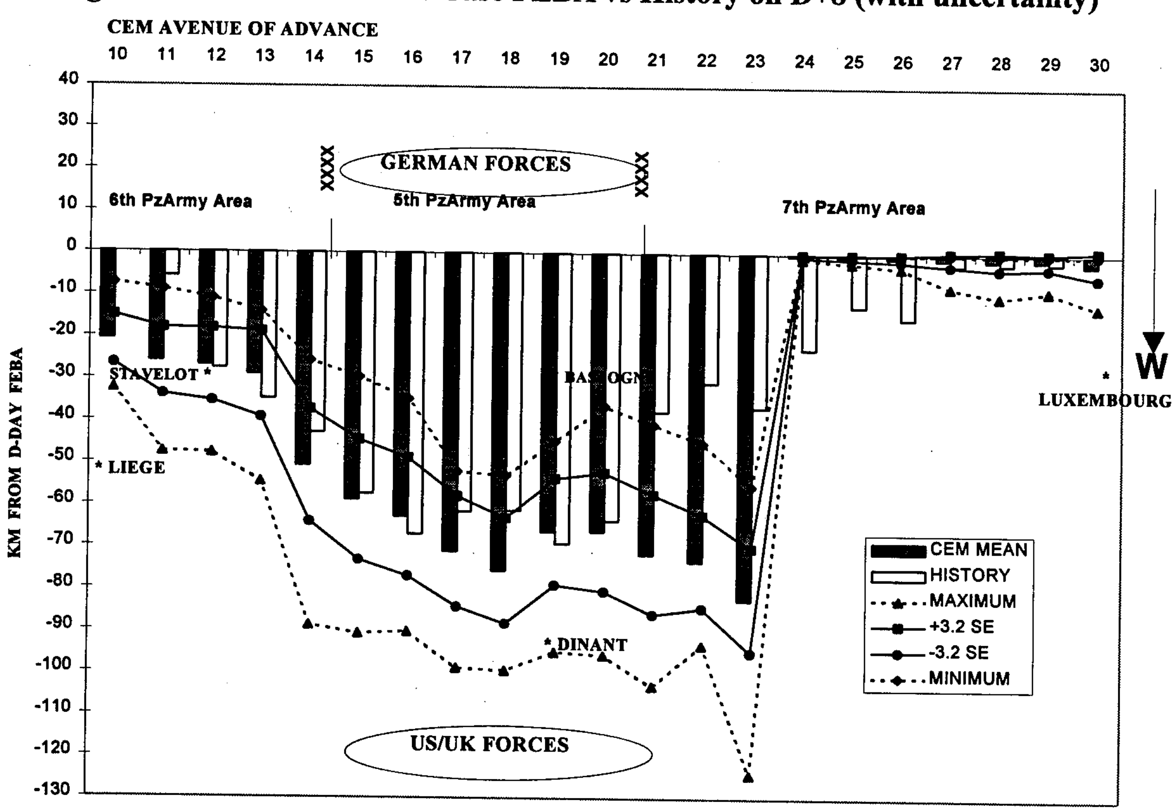


Figure F-3. STOCEM Base Case FEBA vs History on D+12 (with uncertainty)

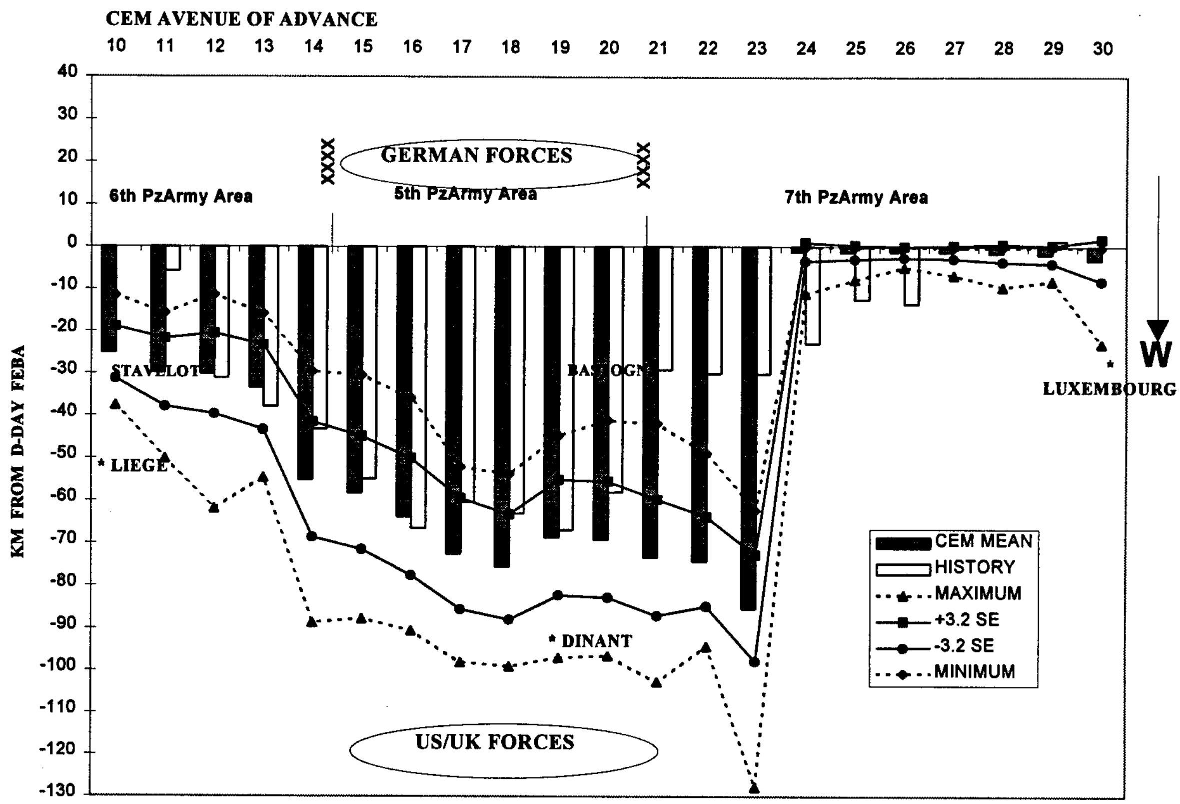


Figure F-4. STOCEM Base Case FEBA vs History on D+16 (with uncertainty)

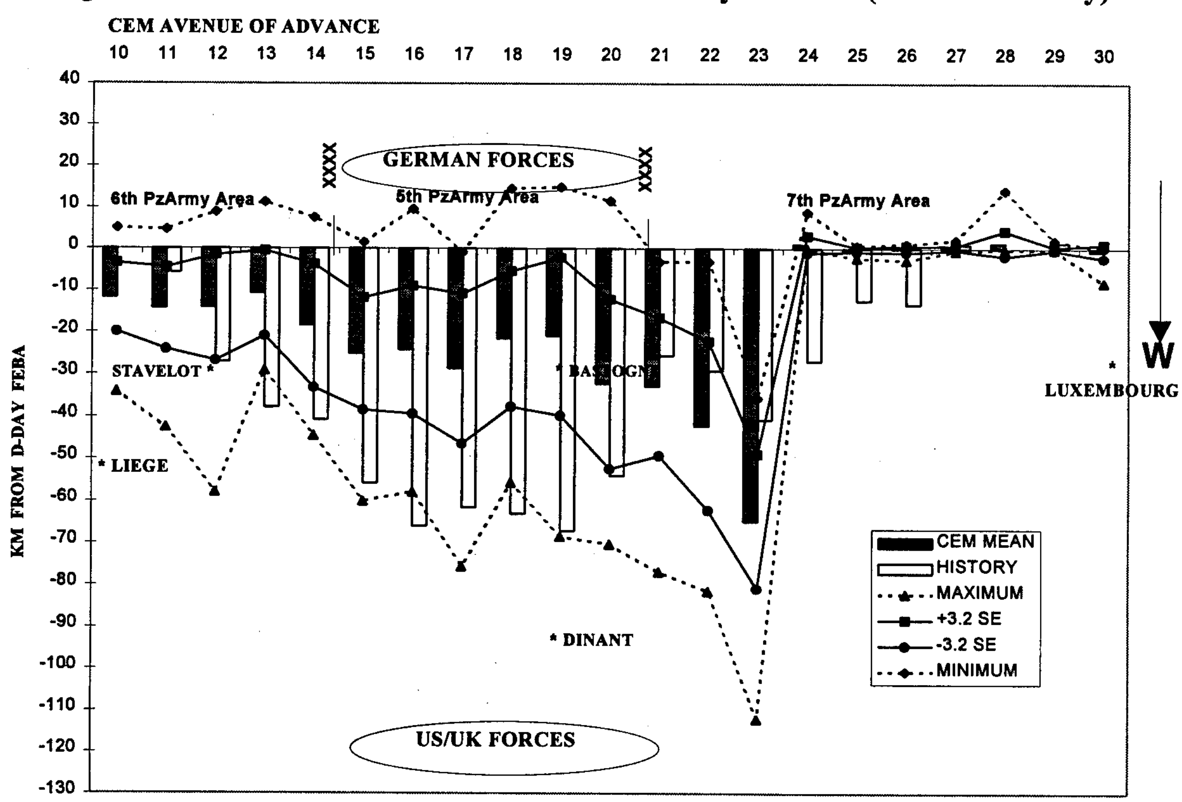


Figure F-5. STOCEM Base Case FEBA vs History on D+20 (with uncertainty)

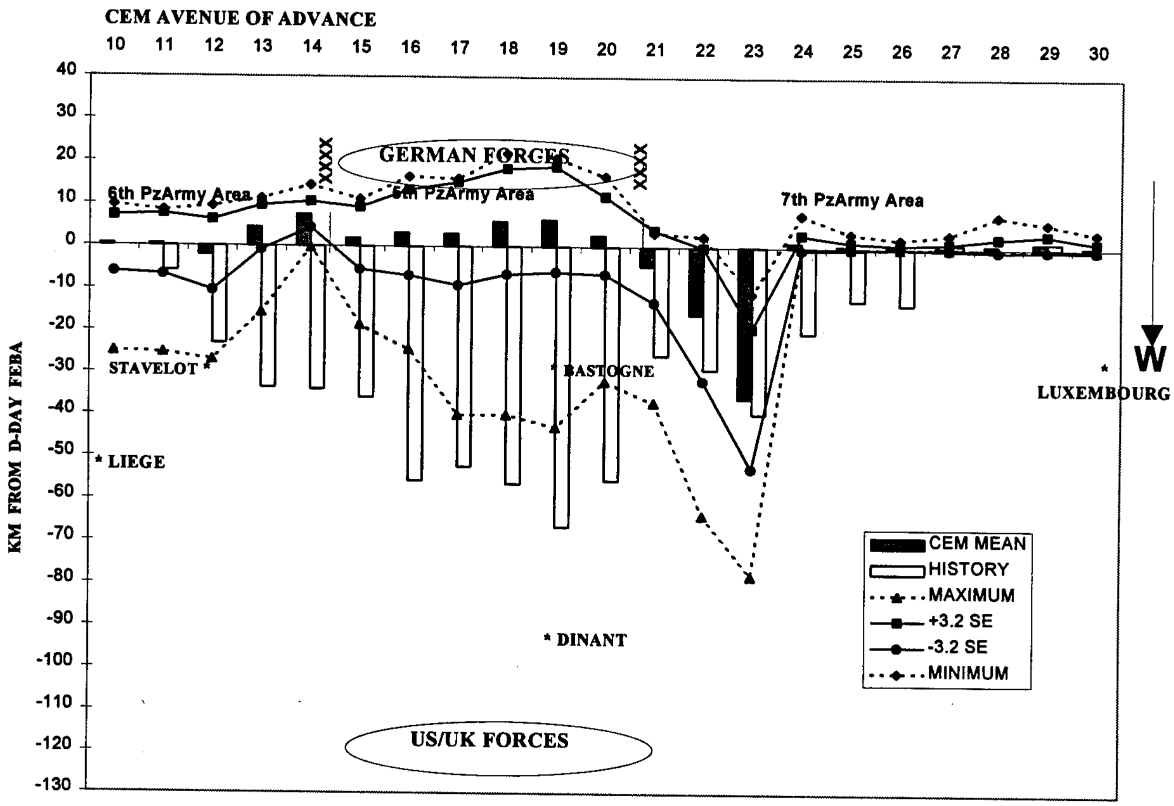


Figure F-6. STOCEM Base Case FEBA vs History on D+24 (with uncertainty)

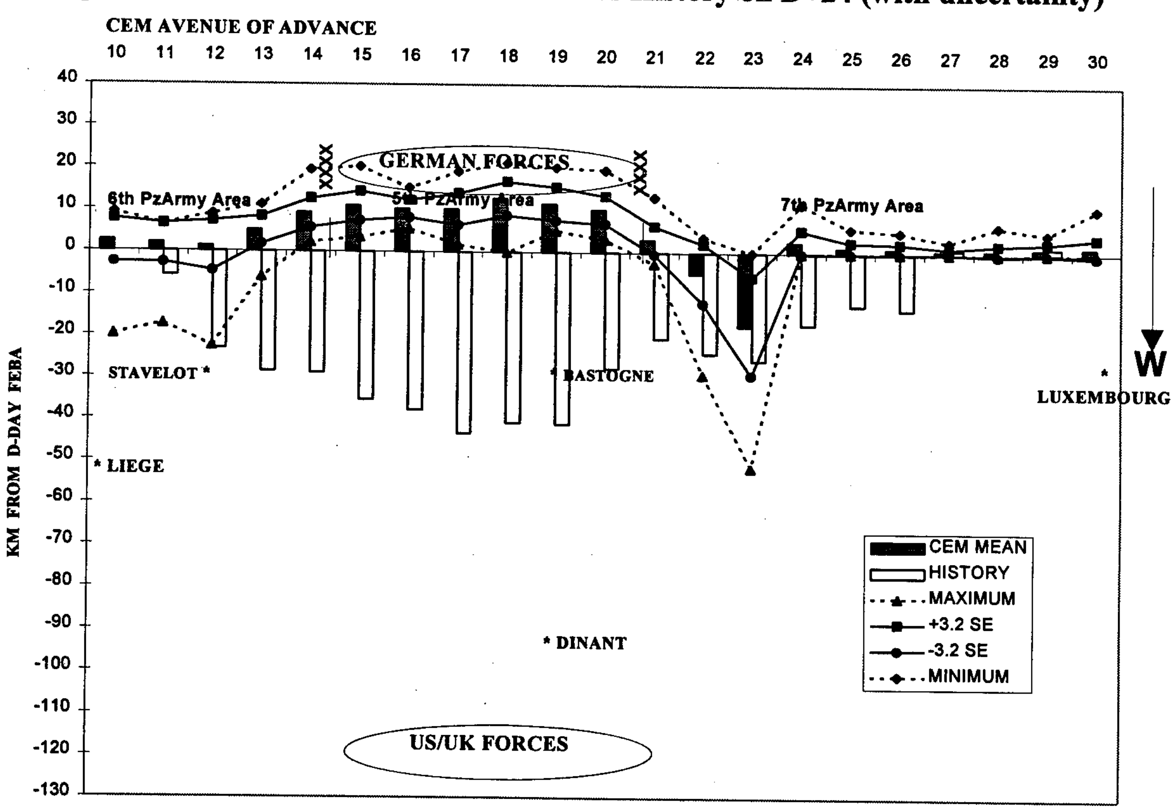


Figure F-7. STOCEM Base Case FEBA vs History on D+28 (with uncertainty)

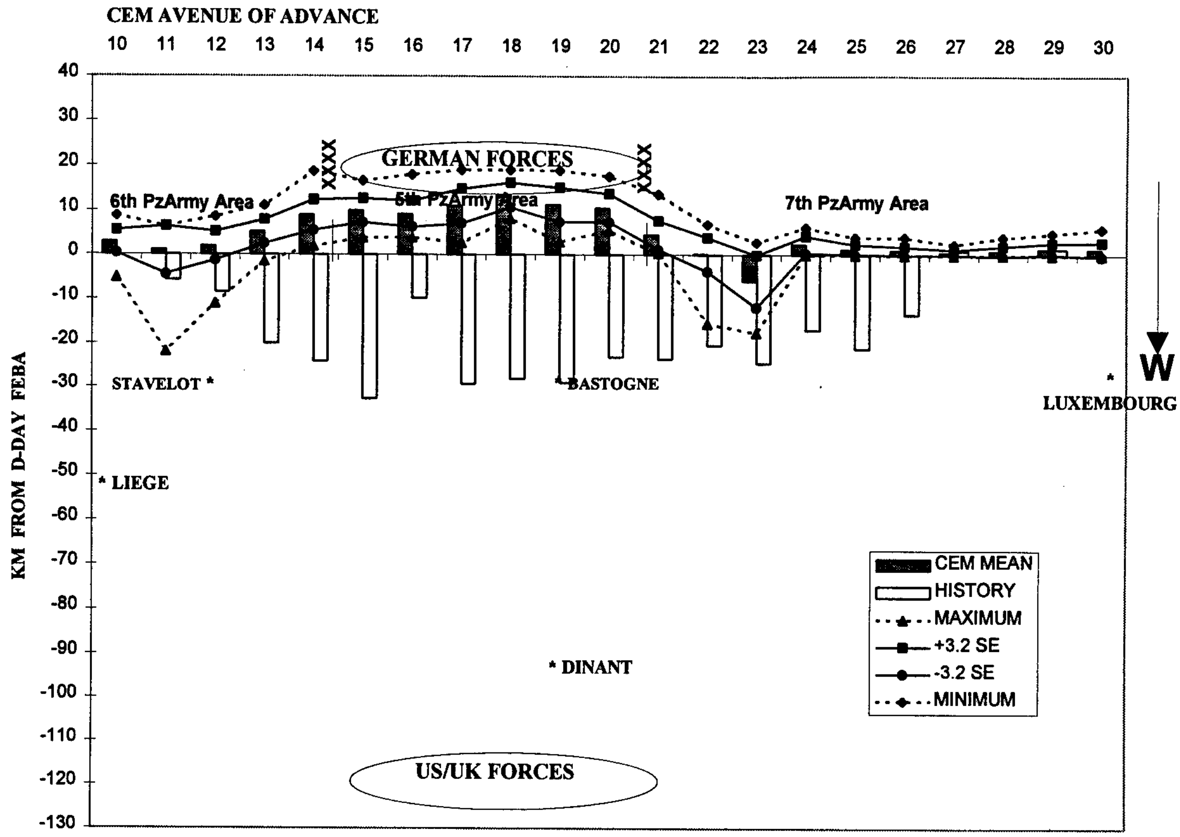


Figure F-8. STOCEM Base Case FEBA vs History on D+32 (with uncertainty)

F-4. EXCURSION CASE FEBA RESULTS. Figures F-9 though F-16 compare the Base History FEBA with the STOCEM excursion case FEBA in a Cartesian (x-,y-) theater representation at 4-day intervals throughout the campaign. For STOCEM, the measures of simulation uncertainty defined in Chapter 2 are shown, along with the average FEBA progress. For the historical results, only the Base History FEBA is shown.

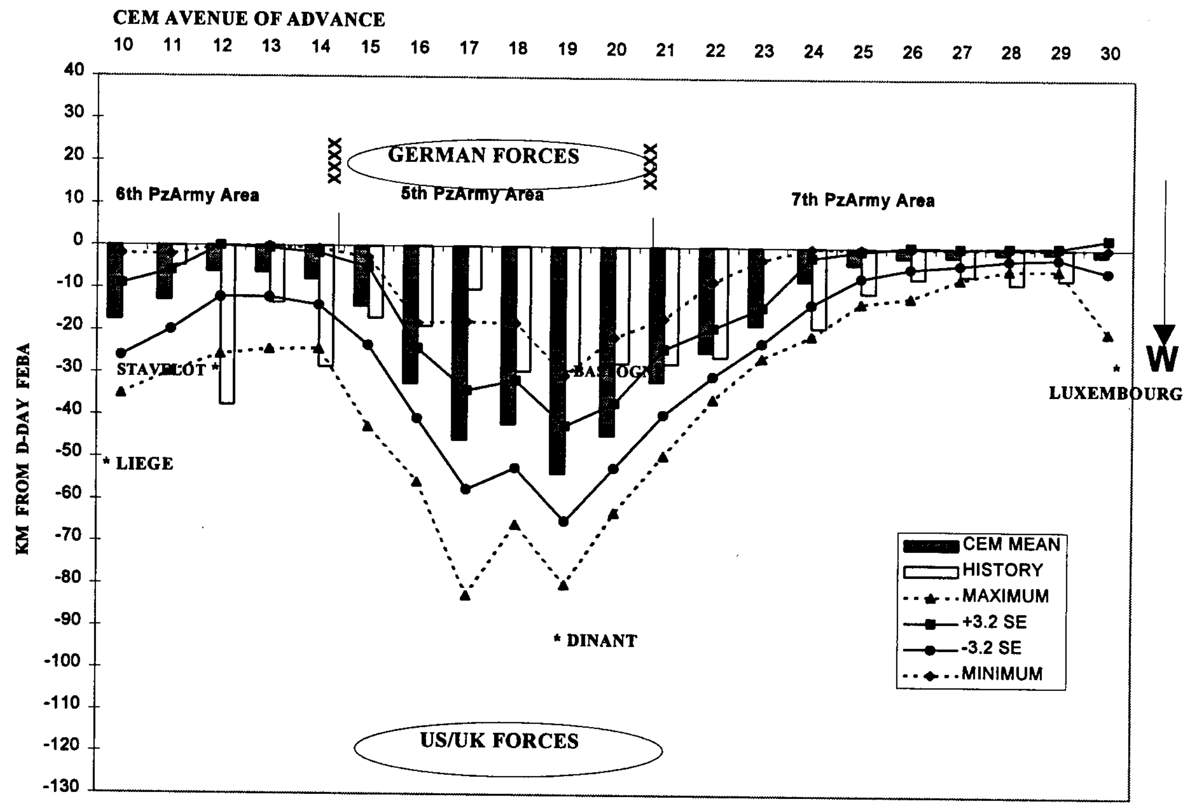


Figure F-9. STOCEM Excursion Case FEBA vs History on D+4 (with uncertainty)

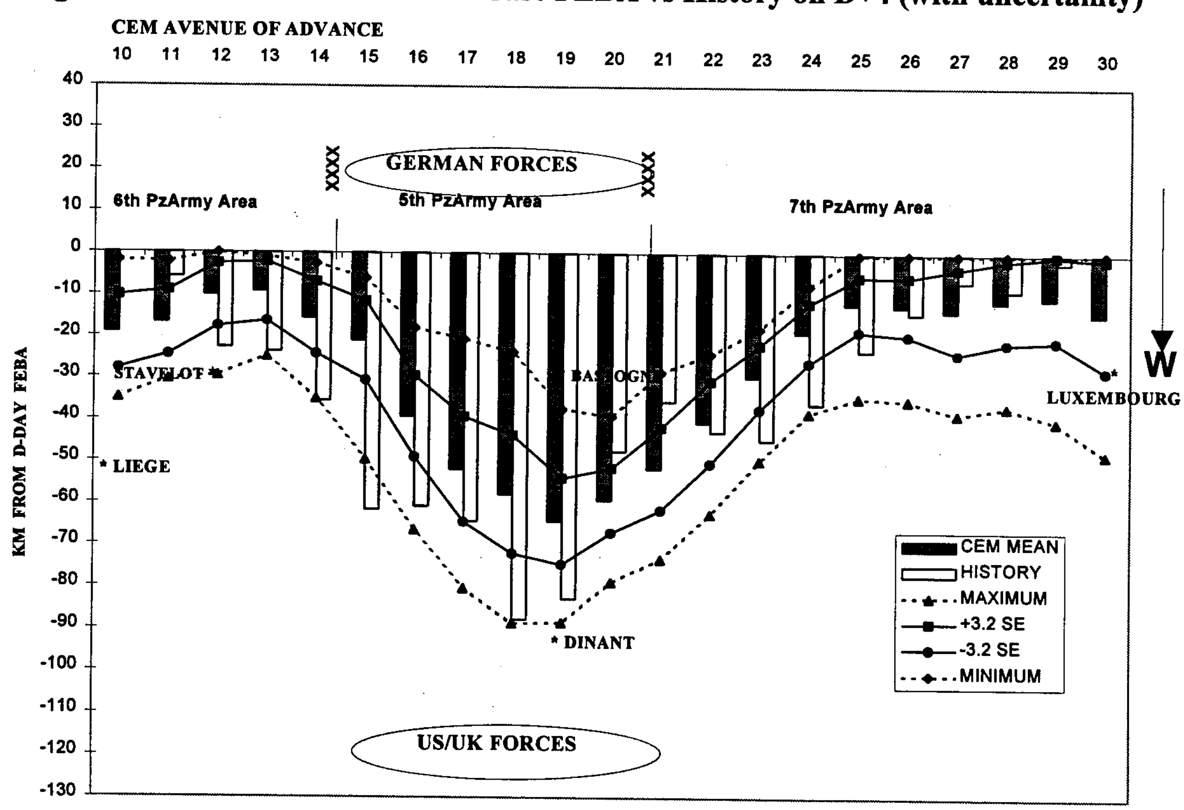


Figure F-10. STOCEM Excursion Case FEBA vs History on D+8 (with uncertainty)

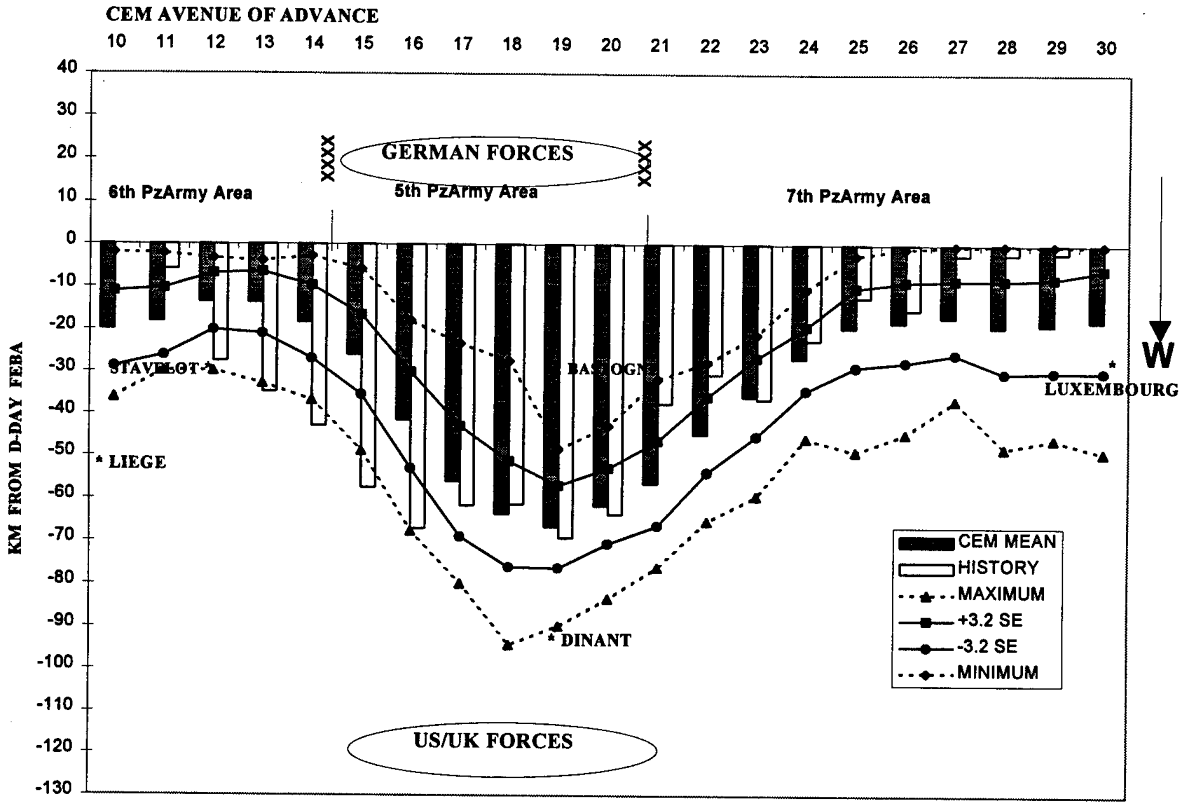


Figure F-11. STOCEM Excursion Case FEBA vs History on D+12 (with uncertainty)

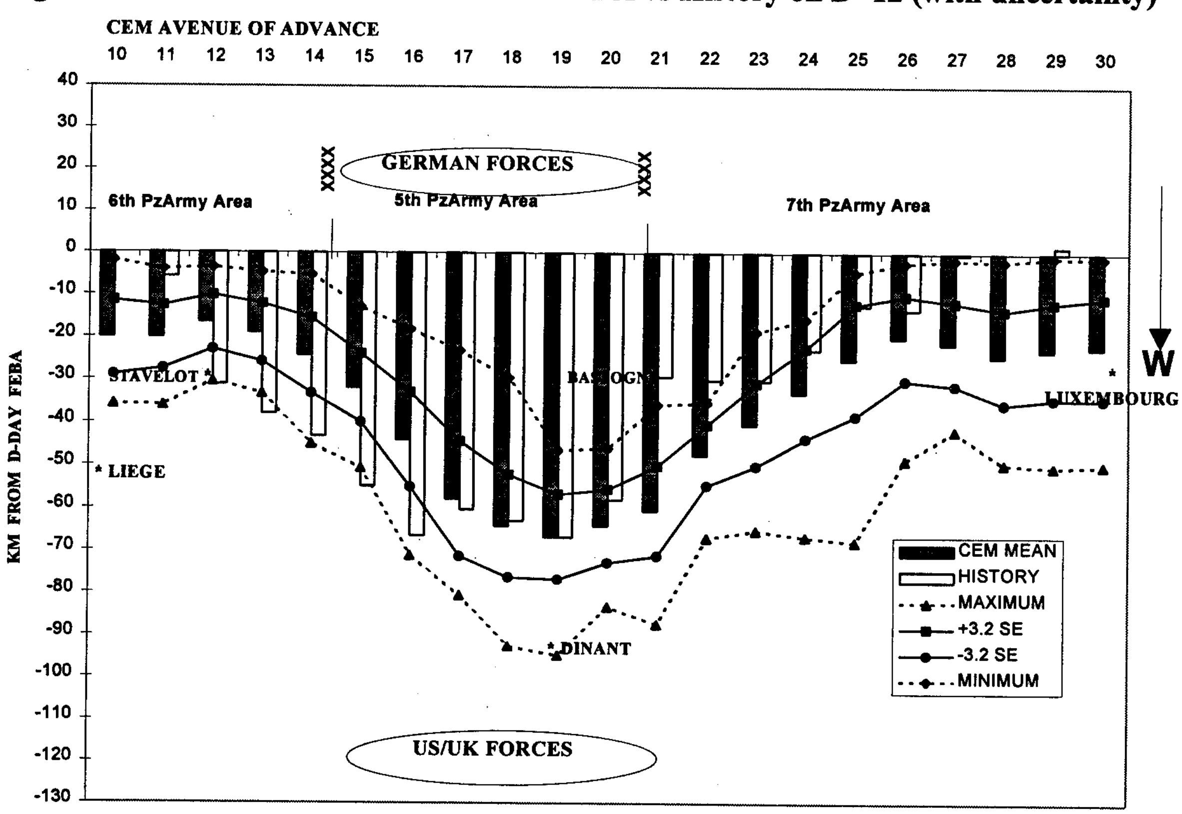


Figure F-12. STOCEM Excursion Case FEBA vs History on D+16 (with uncertainty)

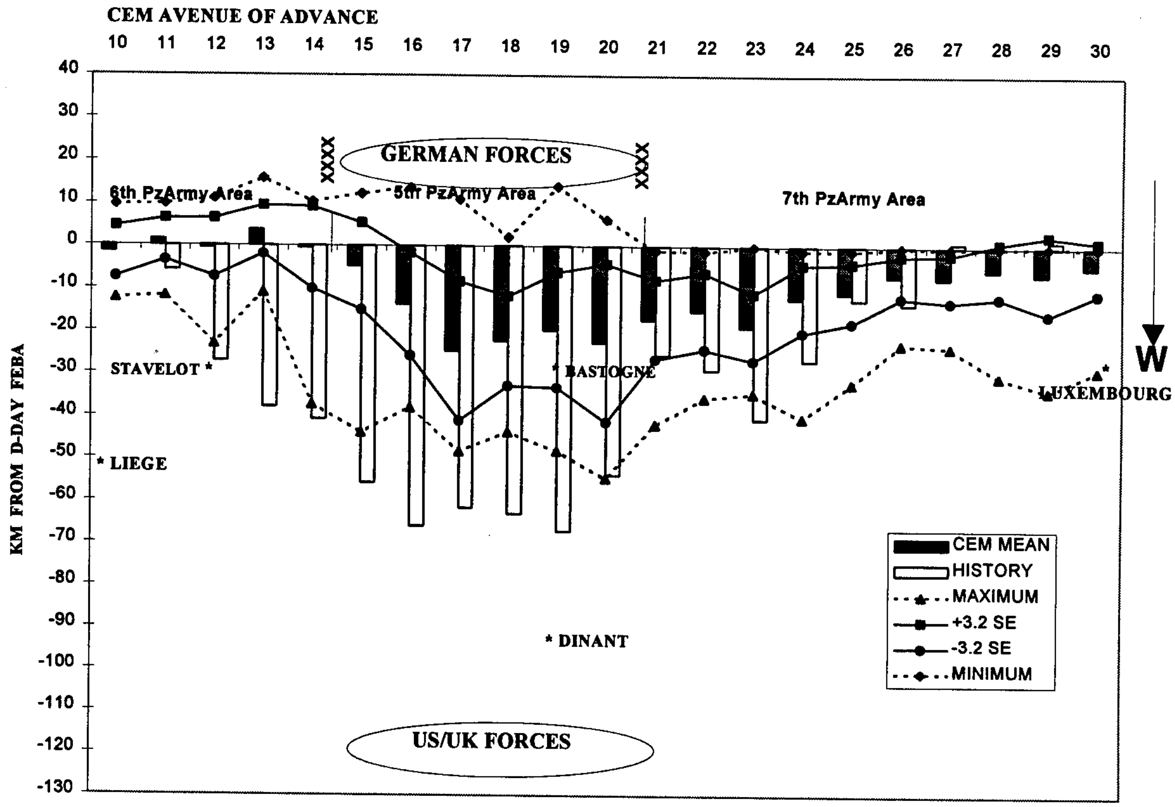


Figure F-13. STOCEM Excursion Case FEBA vs History on D+20 (with uncertainty)

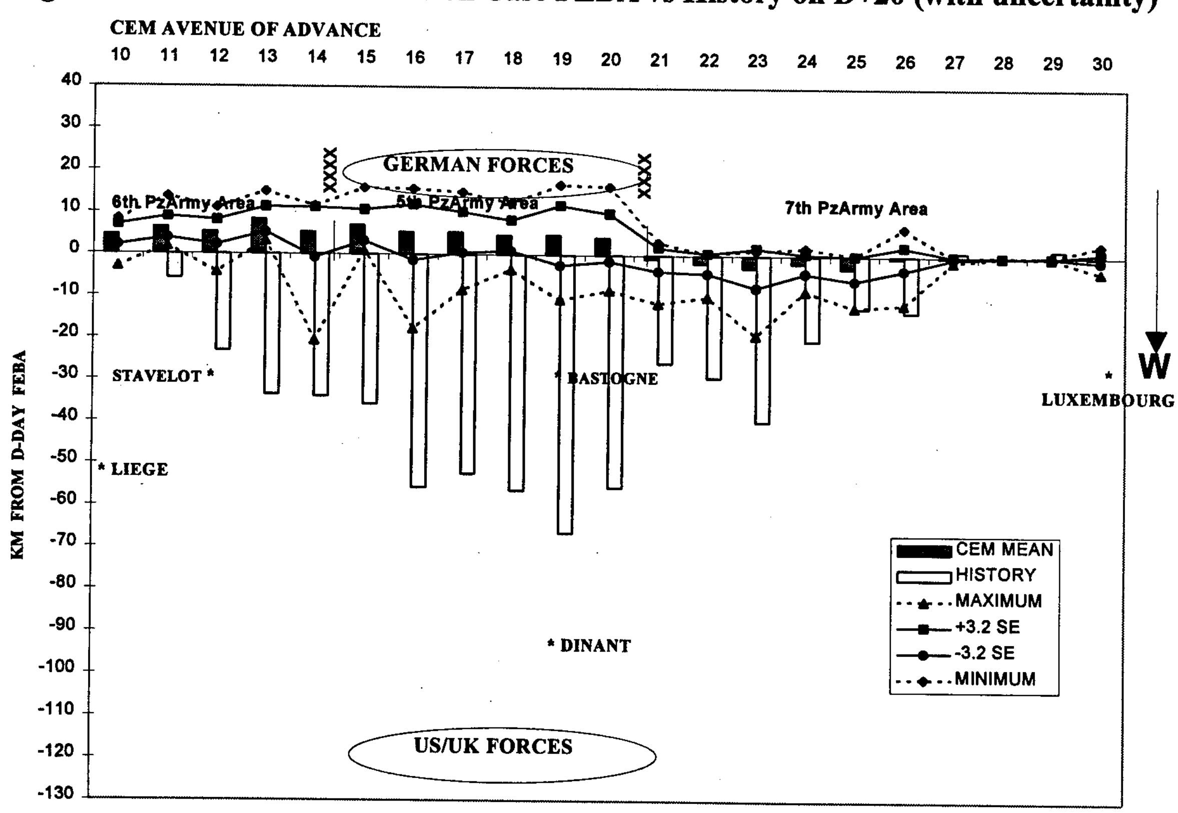


Figure F-14. STOCEM Excursion Case FEBA vs History on D+24 (with uncertainty)

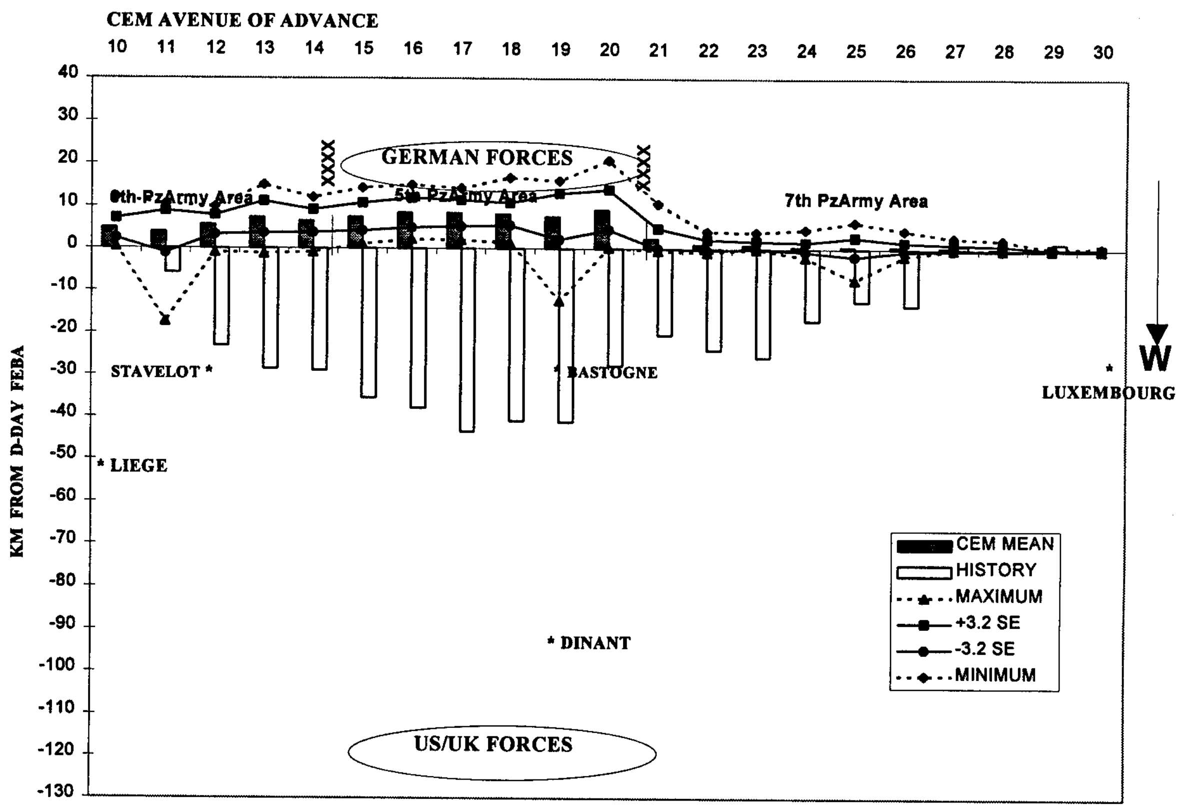


Figure F-15. STOCEM Excursion Case FEBA vs History on D+28 (with uncertainty)

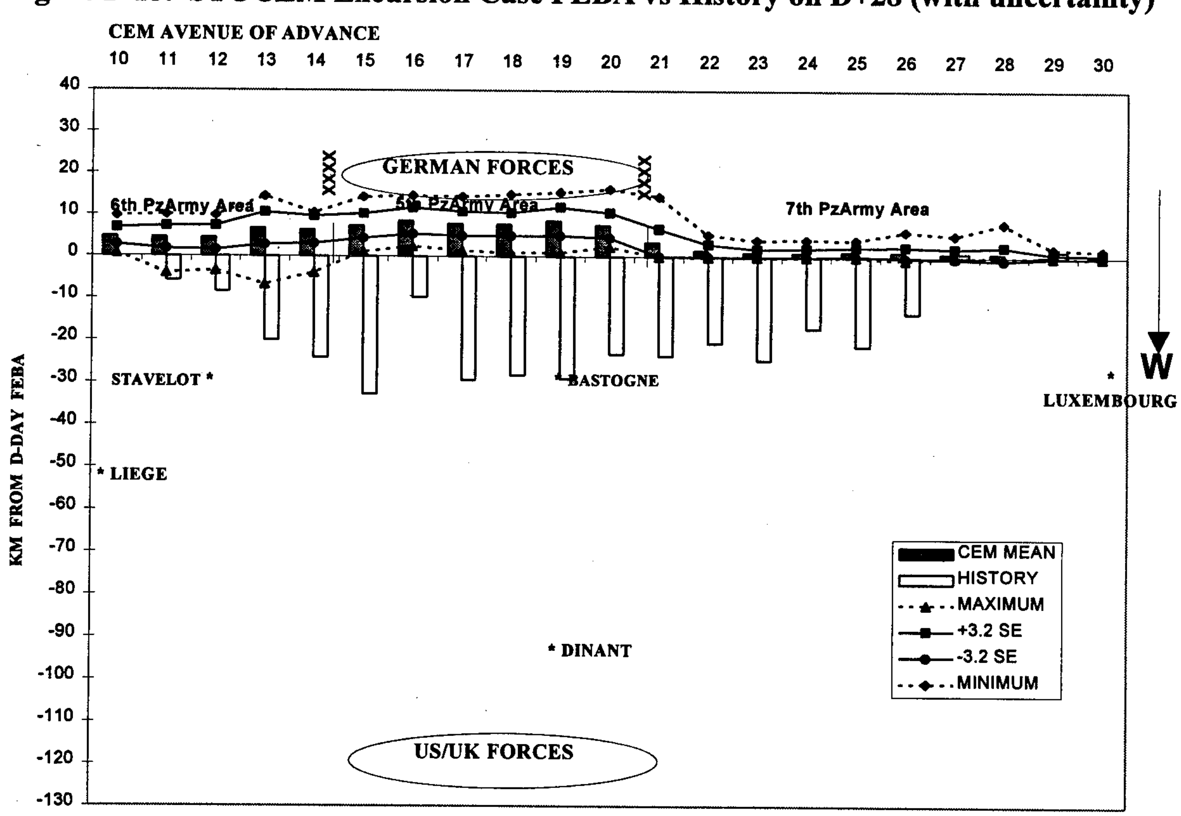


Figure F-16. STOCEM Excursion Case FEBA vs History on D+32 (with uncertainty)

F-5. BASE CASE VERSUS EXCURSION CASE RESULTS. Figures F-17 though F-24 show STOCEM base case FEBA progress, STOCEM excursion case FEBA progress, and historical FEBA progress on a single chart for each specified day. Only average FEBA progress is plotted for STOCEM results.

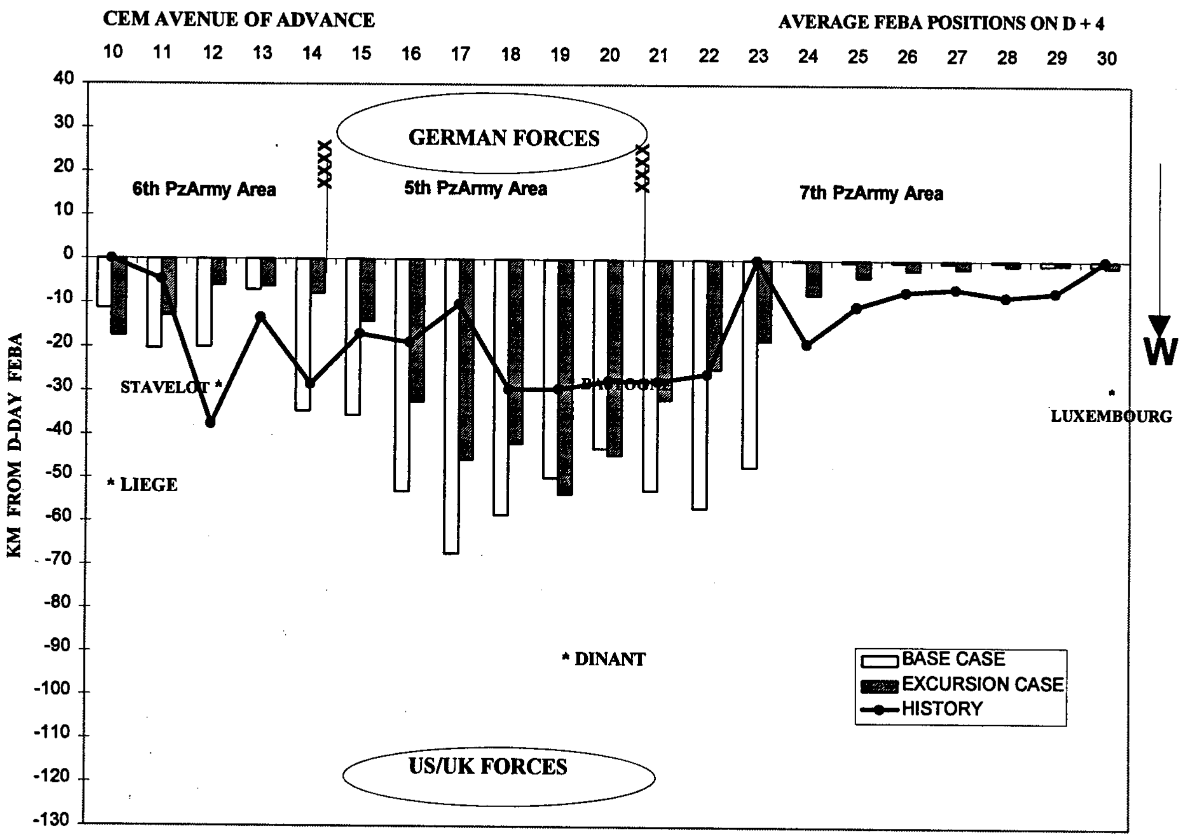


Figure F-17. STOCEM Base Case FEBA vs Excursion Case FEBA on D+4

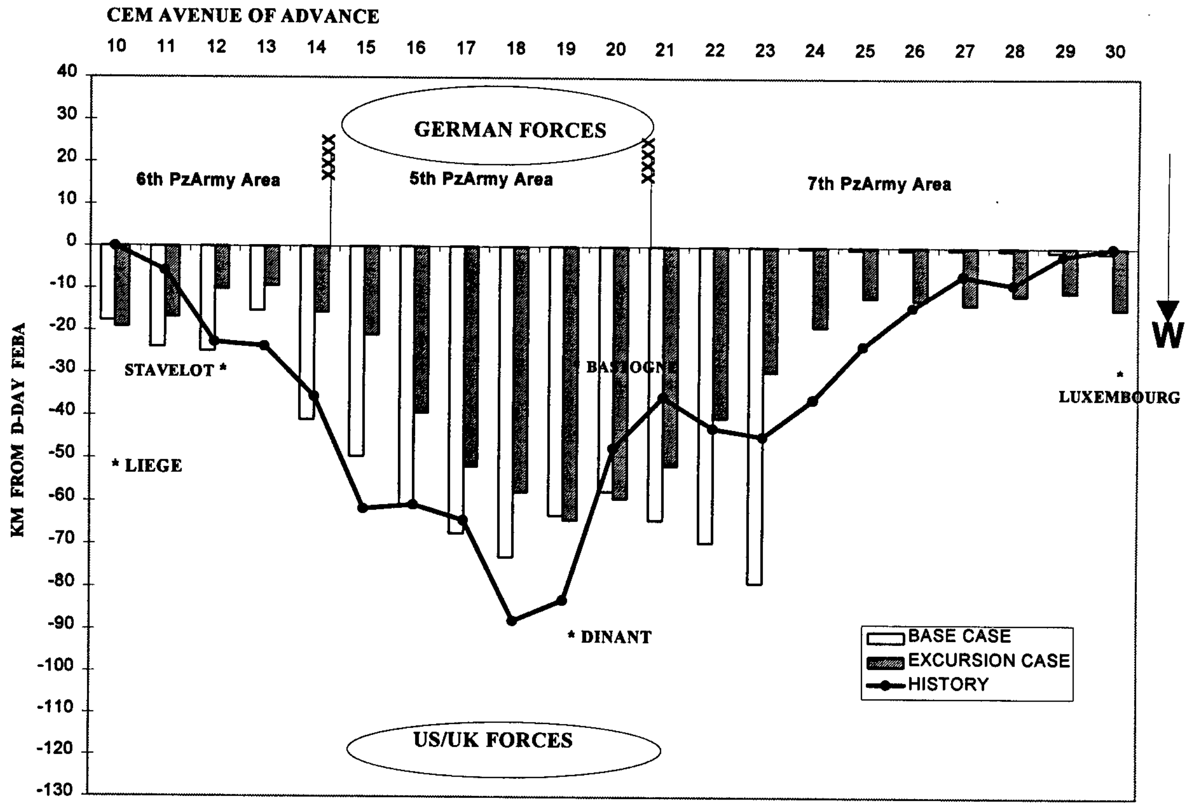


Figure F-18. STOCEM Base Case FEBA vs Excursion Case FEBA on D+8

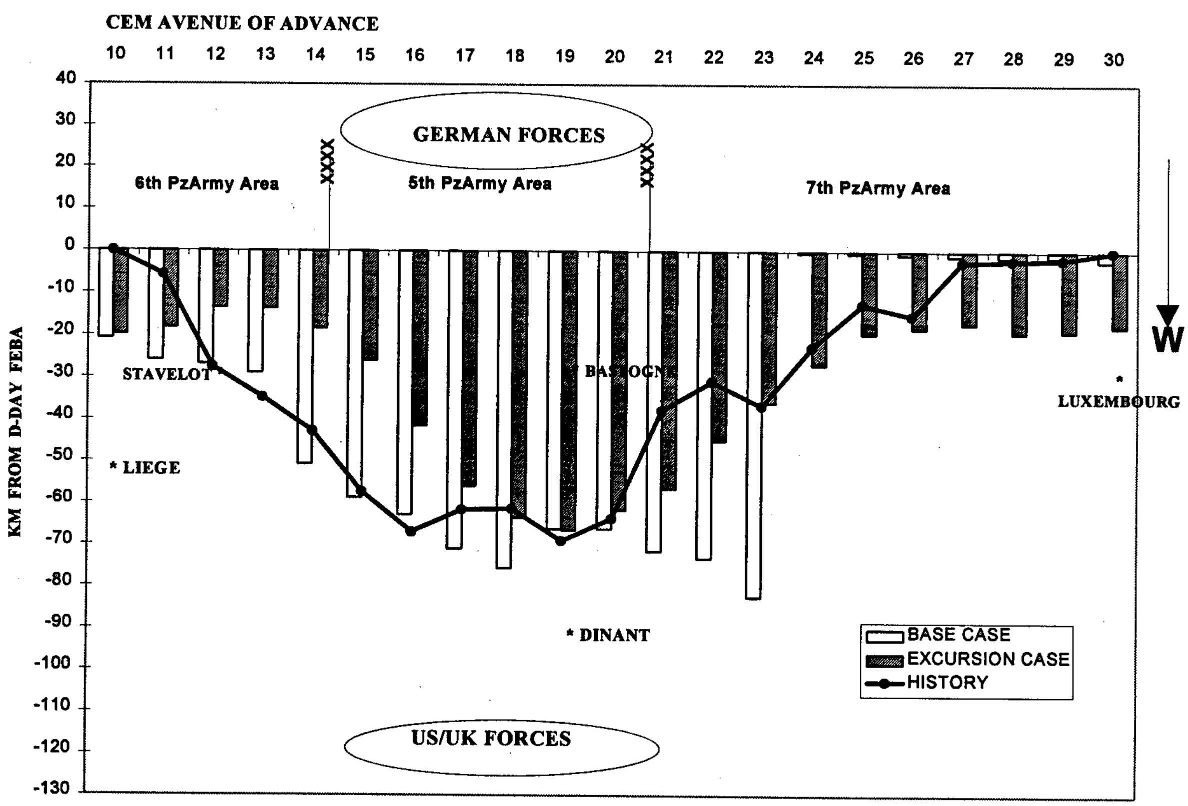


Figure F-19. STOCEM Base Case FEBA vs Excursion Case FEBA on D+12

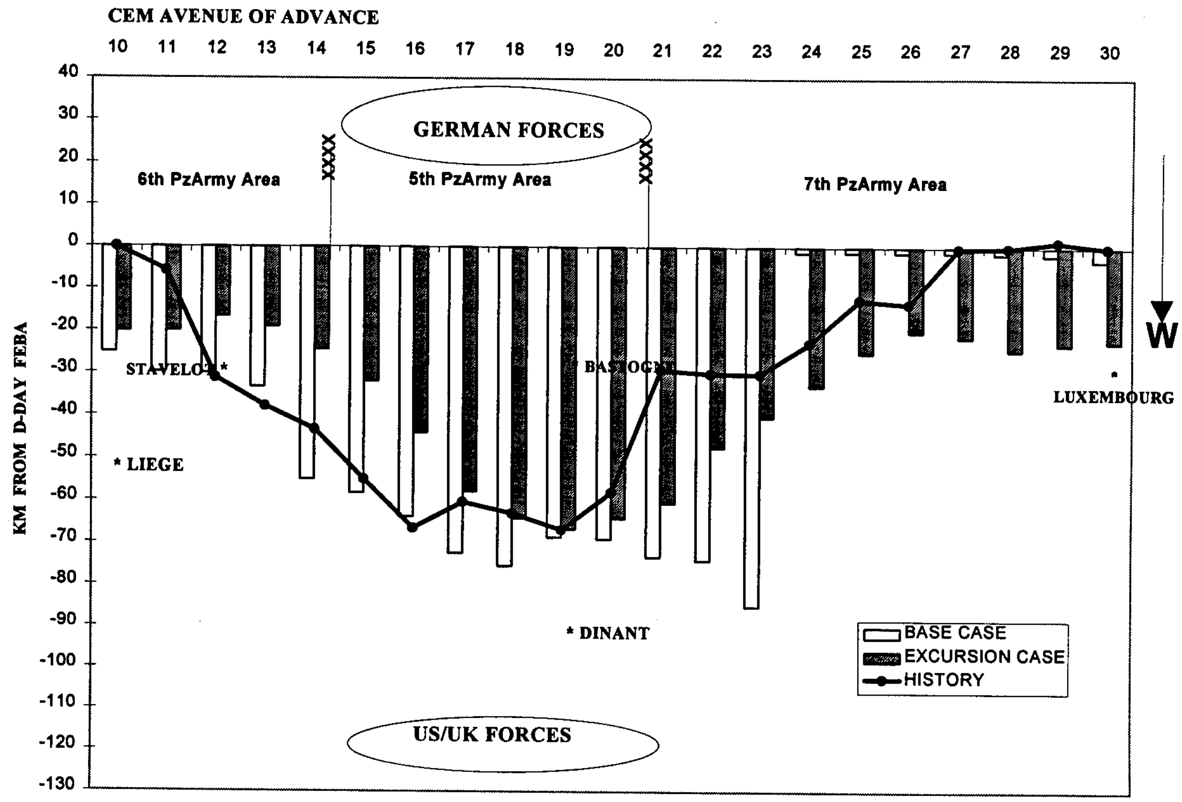


Figure F-20. STOCEM Base Case FEBA vs Excursion Case FEBA on D+16

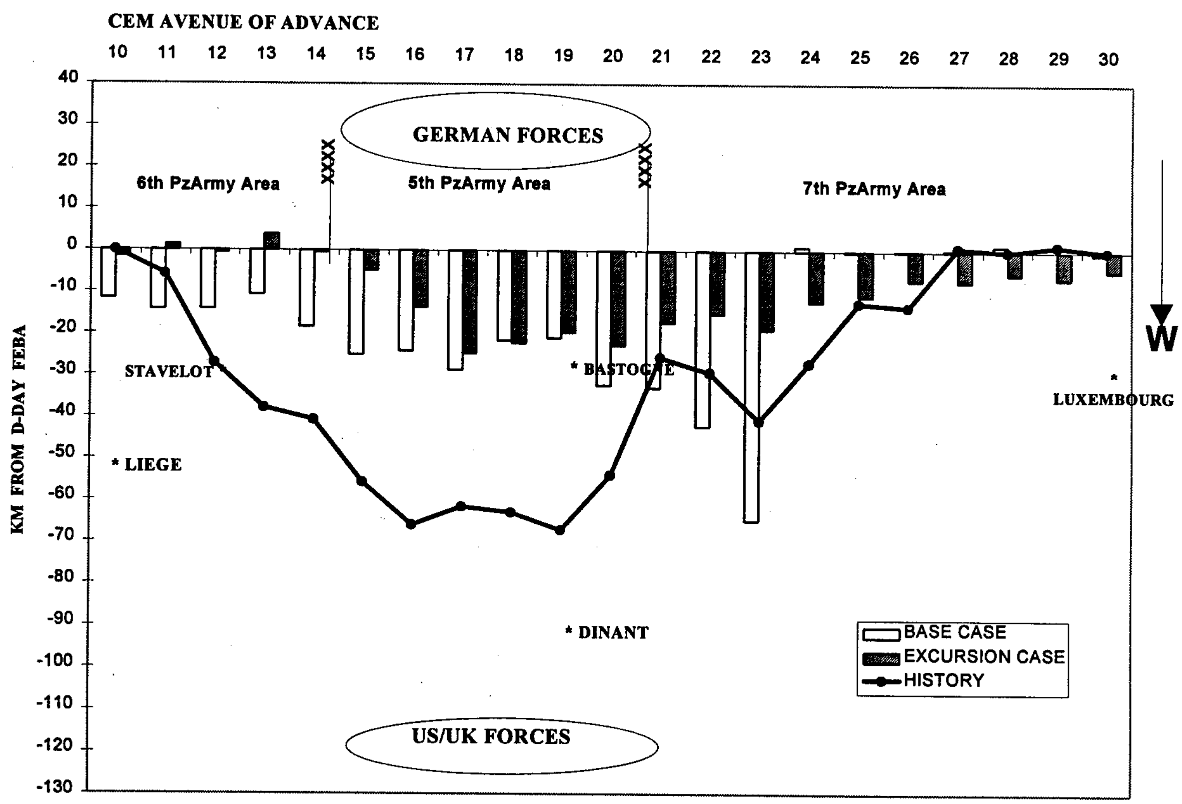


Figure F-21. STOCEM Base Case FEBA vs Excursion Case FEBA on D+20

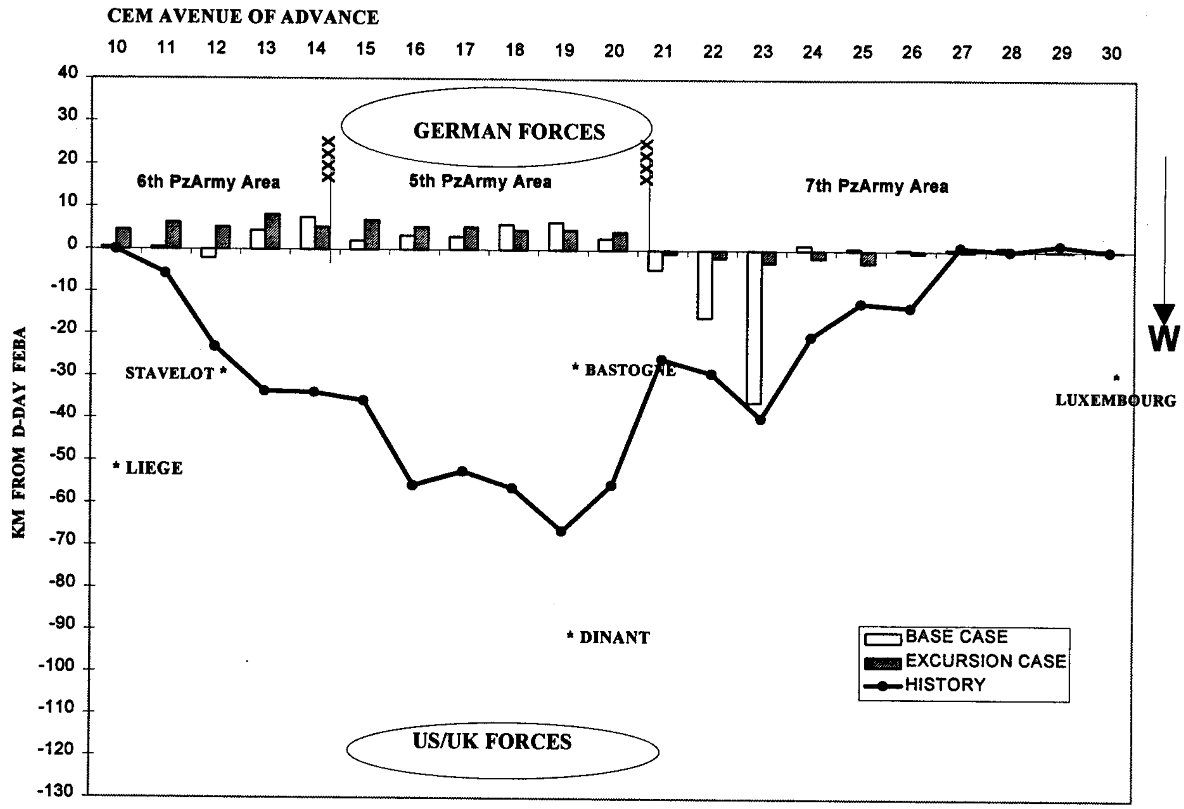


Figure F-22. STOCEM Base Case FEBA vs Excursion Case FEBA on D+24

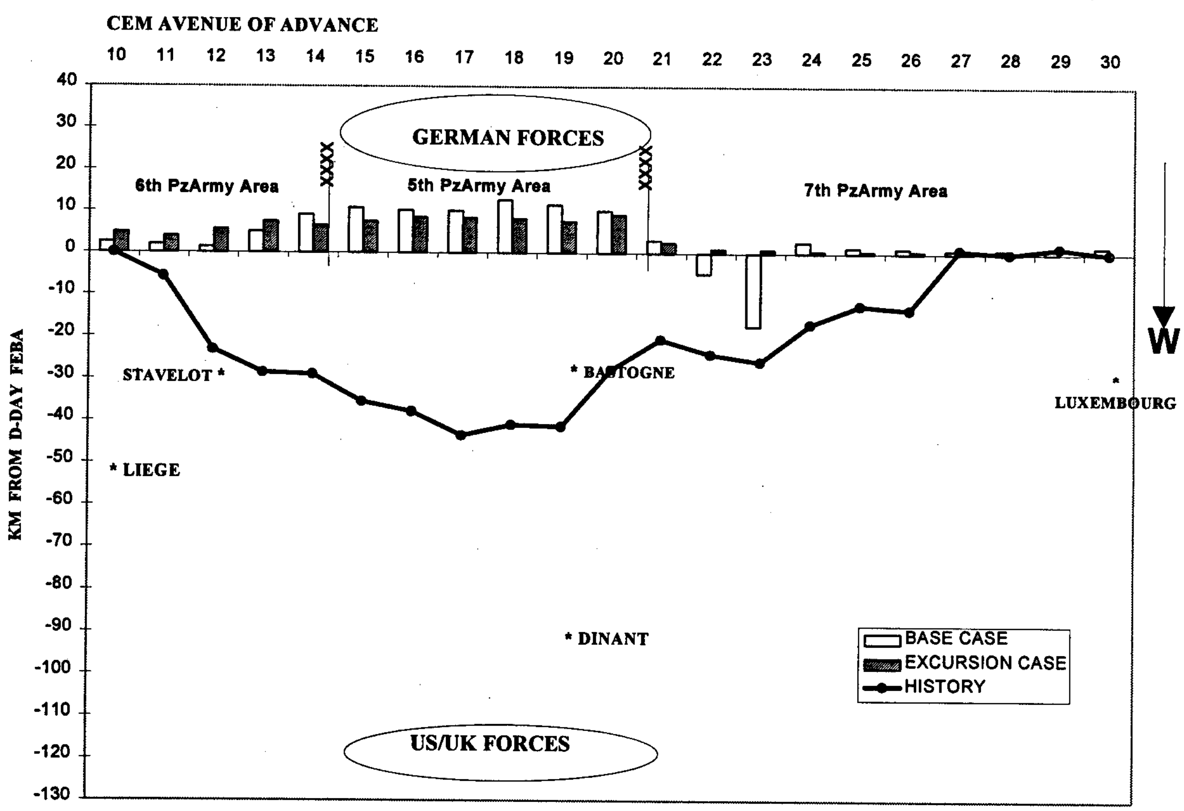


Figure F-23. STOCEM Base Case FEBA vs Excursion Case FEBA on D+28

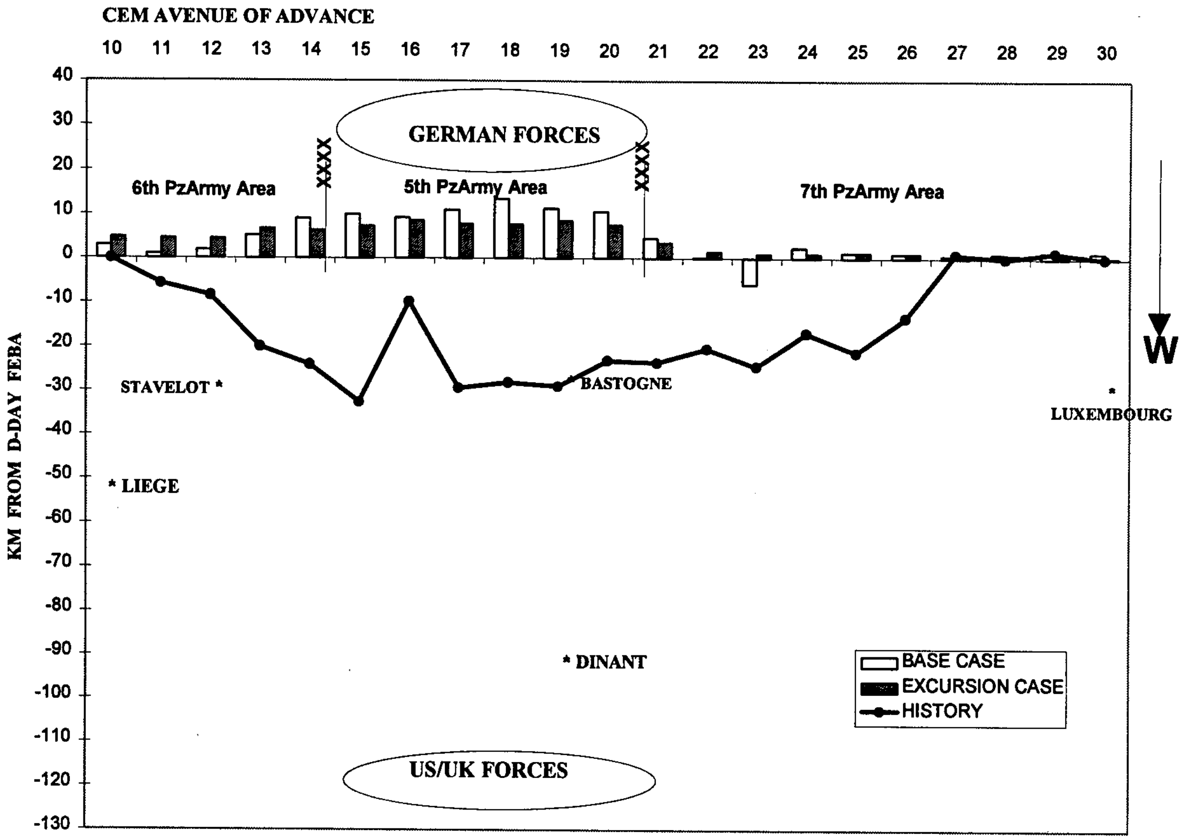


Figure F-24. STOCEM Base Case FEBA vs Excursion Case FEBA on D+32

F-6. AVERAGE FEBA PROGRESS OVER TIME. This paragraph shows STOCEM excursion case analogues of Figures 3-11, 3-12, and 3-13 in the report. Figure F-25 graphically portrays the progress of the average STOCEM excursion case FEBA at 4-day intervals and contrasts it with the Base History FEBA. The line graphs in the figure show average FEBA progress (STOCEM and history) for the entire theater. The bar graphs in the figure show FEBA progress for only 5th Panzer Army area, which comprised most of the historical bulge. The average FEBA progress for the theater on a day is defined as the simple arithmetic average of the FEBA progress on each CEM avenue of advance in the theater. The average FEBA progress for the 5th Panzer Army area on a day is defined analogously except that the average is only over the avenues of advance in the 5th Panzer Army area (avenues 14 through 21). Figures F-26 and F-27 include measures of stochastic uncertainty around the average STOCEM FEBA progress over time charted in Figure F-25. Figure F-26 shows average FEBA progress over the entire theater, while Figure F-27 shows it only over the 5th Panzer Army area. In addition to the average STOCEM FEBA, these figures also show the four measures of STOCEM uncertainty defined in paragraph 2-7. The solid lines labeled +- 3.2 SE are the 99 percent/90 percent confidence limit bounds for the STOCEM average FEBA.

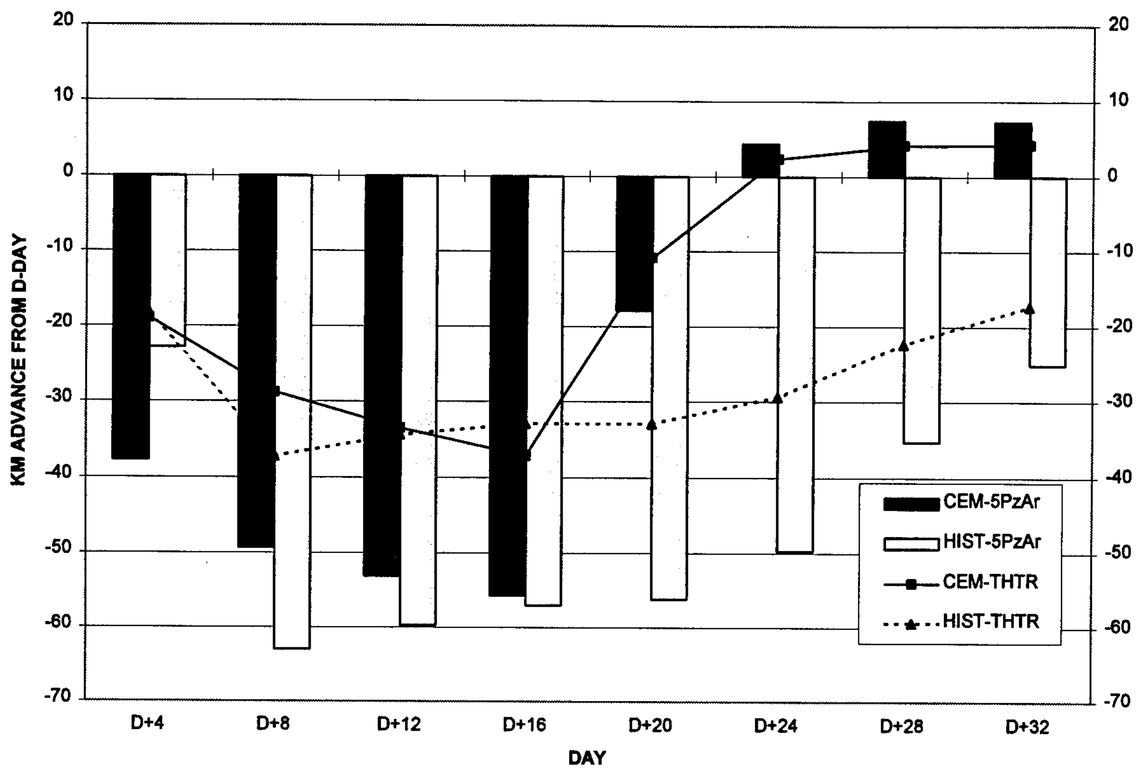


Figure F-25. Average FEBA Progress Over Time in Theater and in 5th Panzer Army Area (STOCEM excursion case)

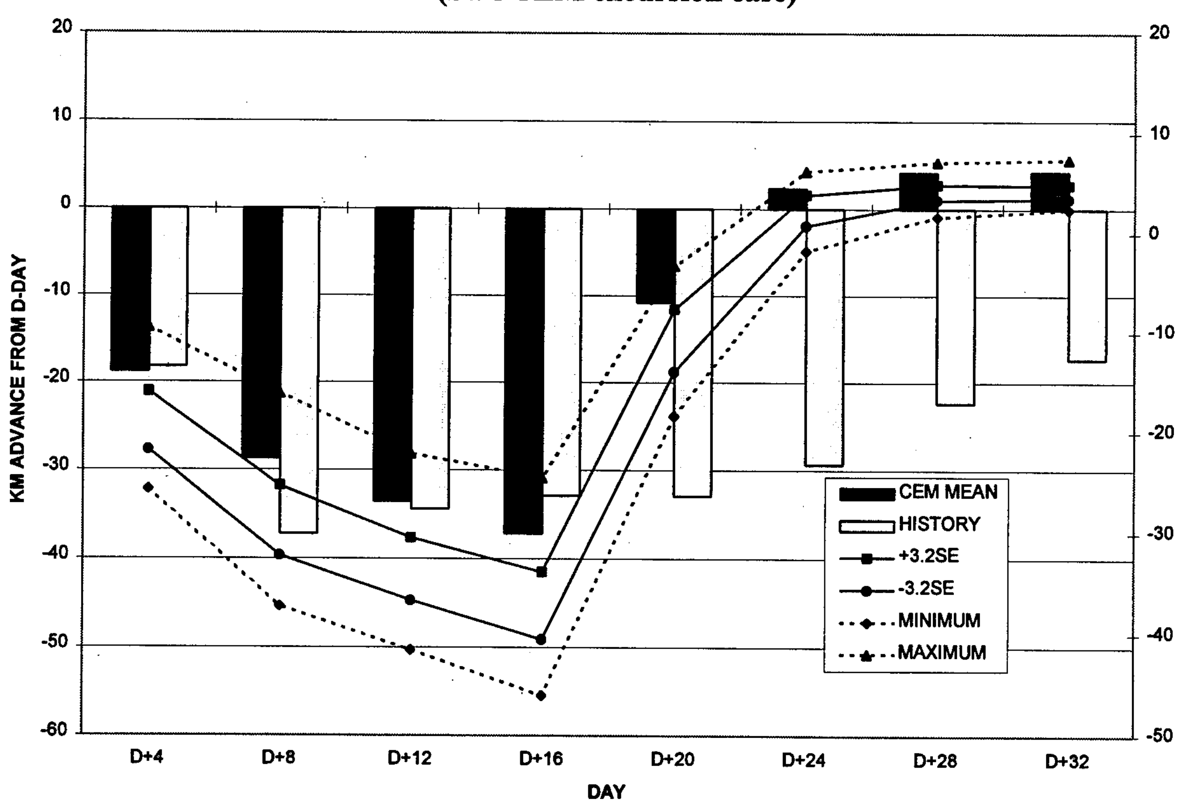


Figure F-26. Average Theater FEBA Progress with Uncertainty (STOCEM excursion case)

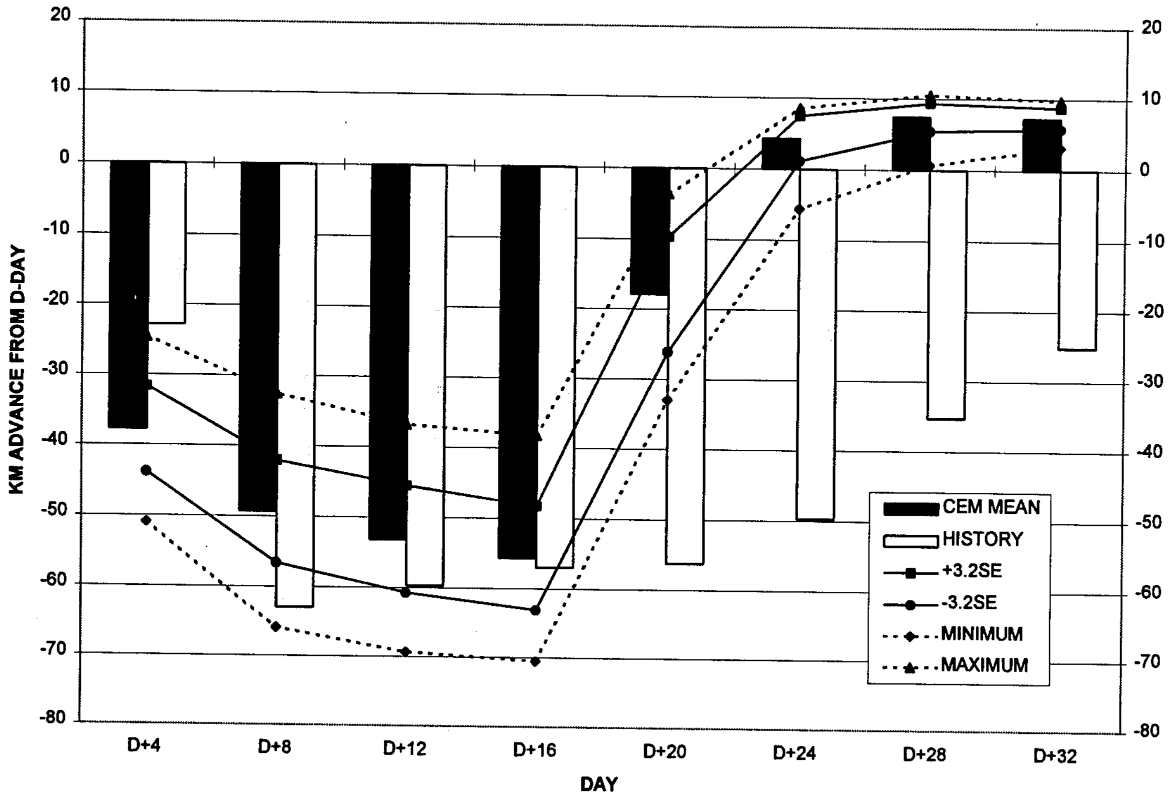


Figure F-27. Average 5th Panzer Army Area FEBA Progress with Uncertainty (STOCEM excursion case)

APPENDIX G

COMPARATIVE SYSTEM LOSSES FOR THE STOCEM EXCURSION CASE

G-1. OVERVIEW. This appendix supplements the weapon system loss results in Chapter 6 of the report. The STOCEM base case and STOCEM excursion case scenarios are as defined in paragraph 2-6 of the report. Losses are defined as destroyed or abandoned weapon systems.

a. History vs STOCEM excursion case. The first two groups of figures compare the STOCEM excursion case simulation with the historical weapon system loss results during the course of the Ardennes Campaign. Both US/UK losses and German losses are shown. The weapon systems represented are categorized into four classes: tanks, APCs, AT/Ms, and artillery. STOCEM and historical total system losses in each weapon class are depicted at 4-day intervals for each force. Both cumulative losses and losses within each 4-day period are charted.

b. STOCEM Base Case vs STOCEM excursion case. The third group of figures compares the STOCEM excursion case simulation results with STOCEM base case simulation results. STOCEM total system losses in each weapon class are depicted, at 4-day intervals, for each force.

c. Overview Comparison Across Weapon System Classes. The last group of figures shows the ratio of cumulative excursion case STOCEM mean losses to cumulative historical losses across all four weapon classes and the fraction of total STOCEM excursion case mean losses which occur in each 4-day period of the campaign. Analogous figures for the STOCEM base case and for history are in Figures 5-17 through 5-22 of the report

G-2. CUMULATIVE LOSSES. Figures G-1 through G-4 show excursion case STOCEM and historical cumulative (since D-day) total US/UK weapon systems lost (destroyed or abandoned) at 4-day intervals. Figures G-5 through G-8 show analogous German loss results. Each chart shows, for STOCEM, the mean value, the max/min band, and the 99 percent/90 percent confidence limit band for cumulative losses of a specified type weapon system.

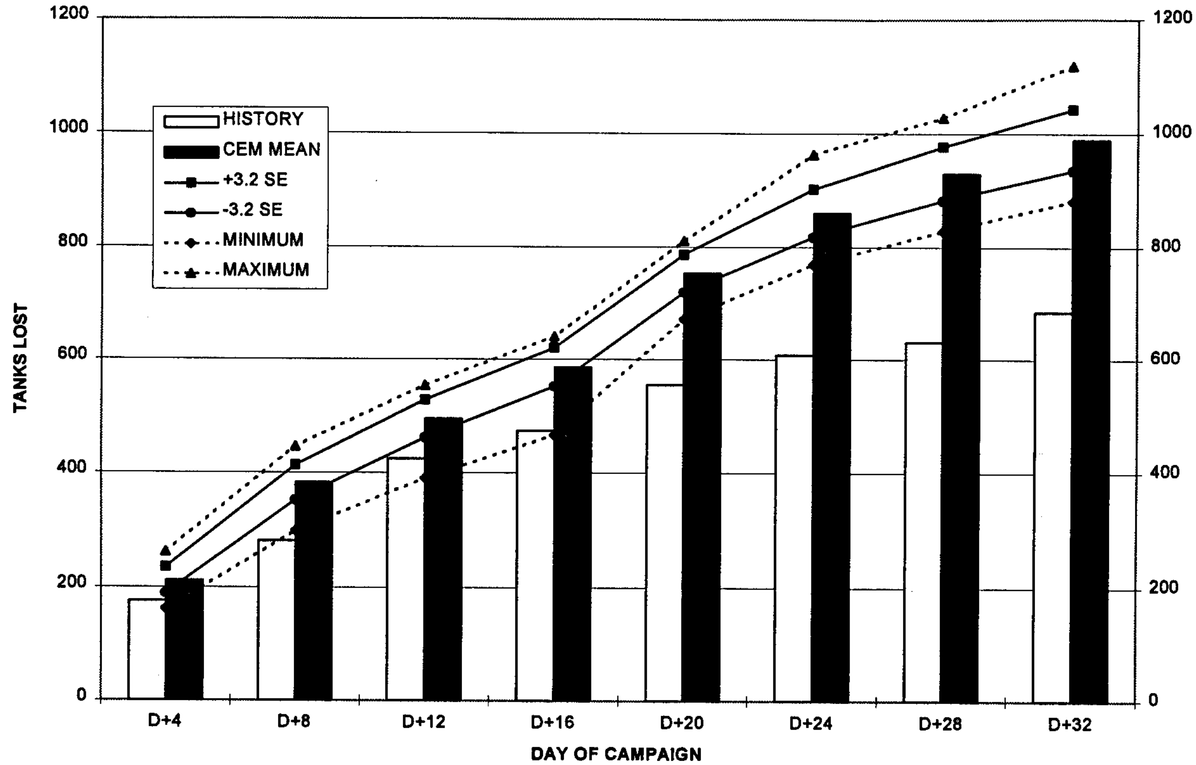


Figure G-1. Cumulative US/UK Tank Losses (History vs STOCEM excursion case)

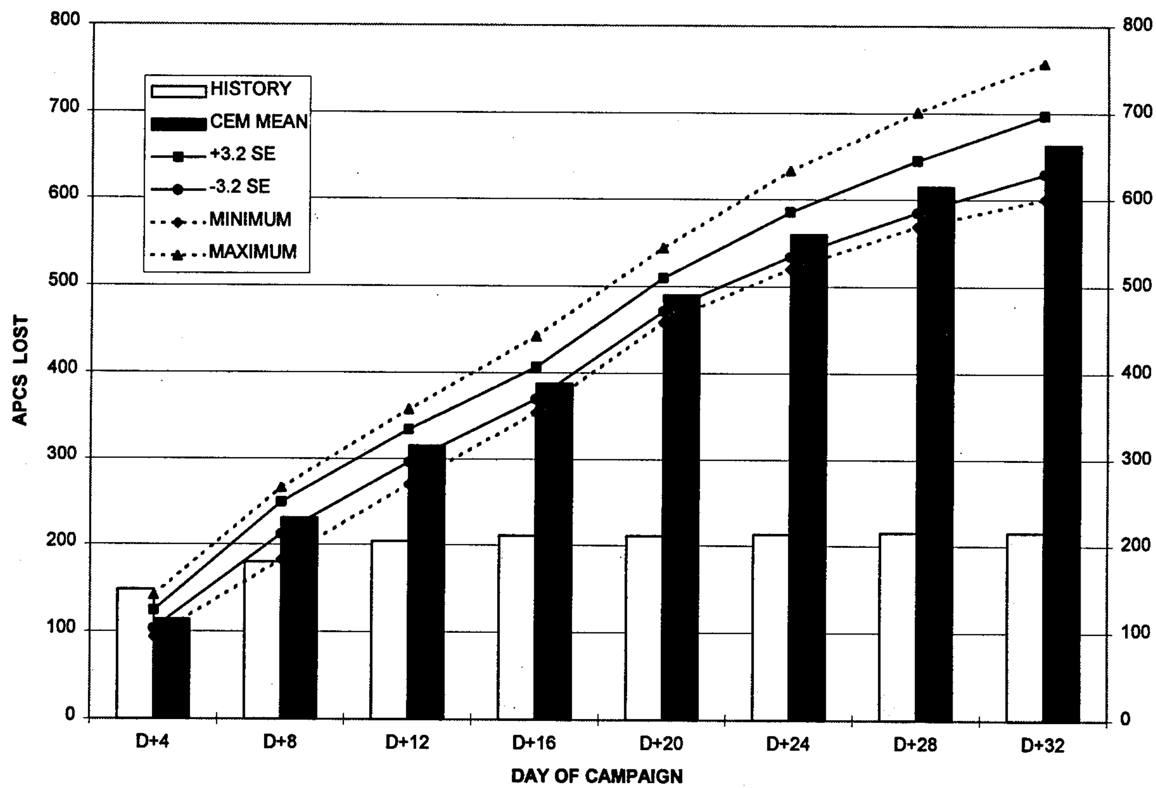


Figure G-2. Cumulative US/UK APC Losses (History vs STOCEM excursion case)

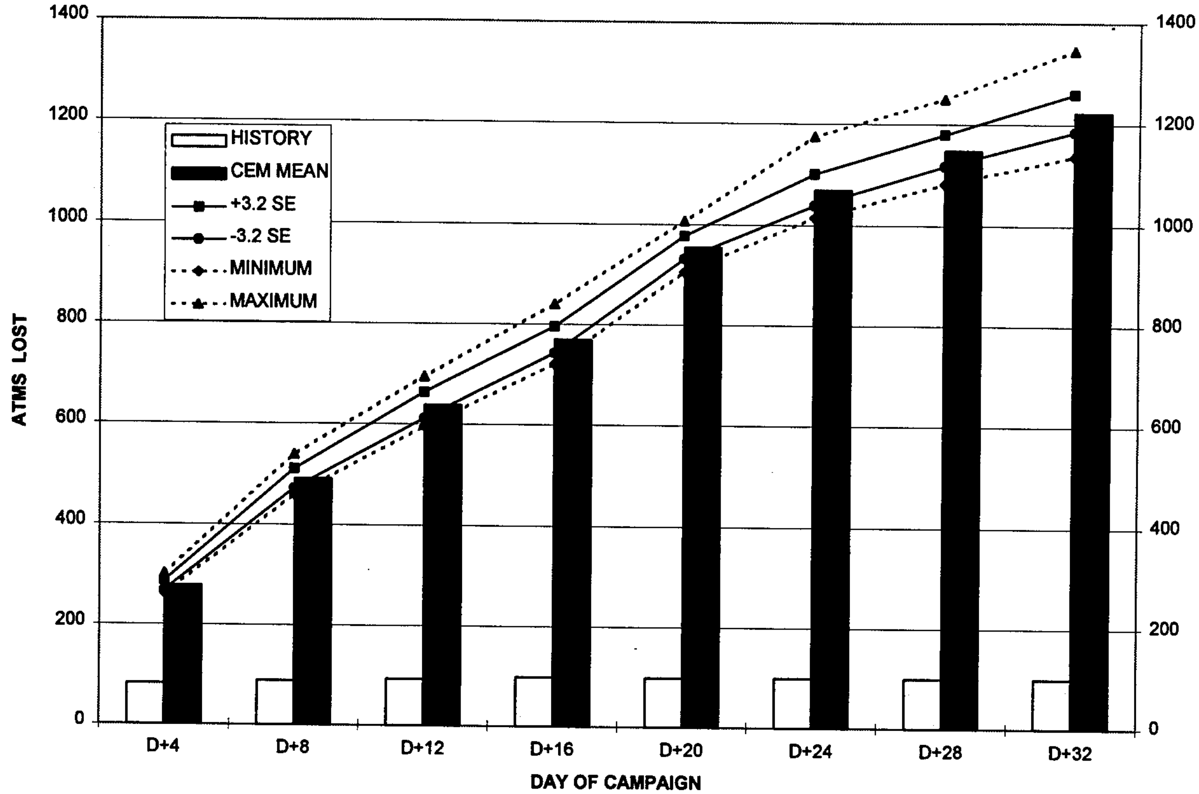


Figure G-3. Cumulative US/UK AT/M Losses (History vs STOCEM excursion case)

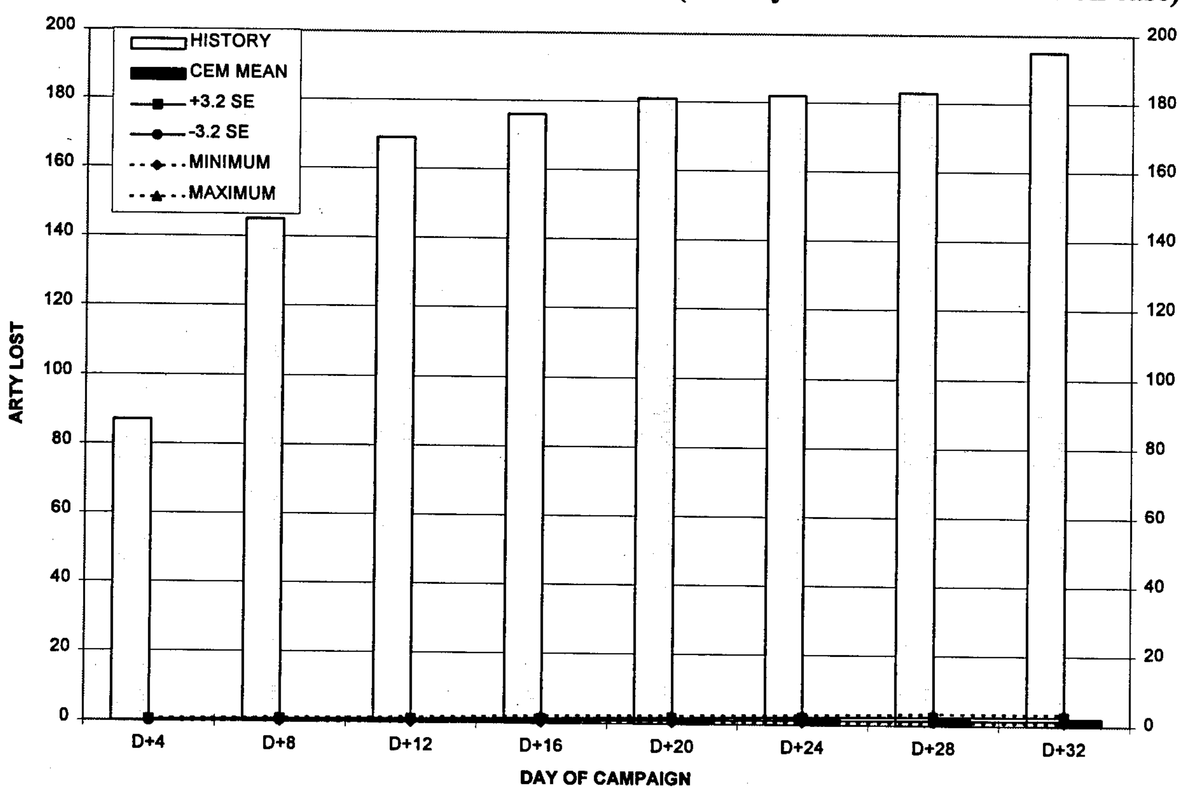


Figure G-4. Cumulative US/UK Artillery Losses (History vs STOCEM excursion case)

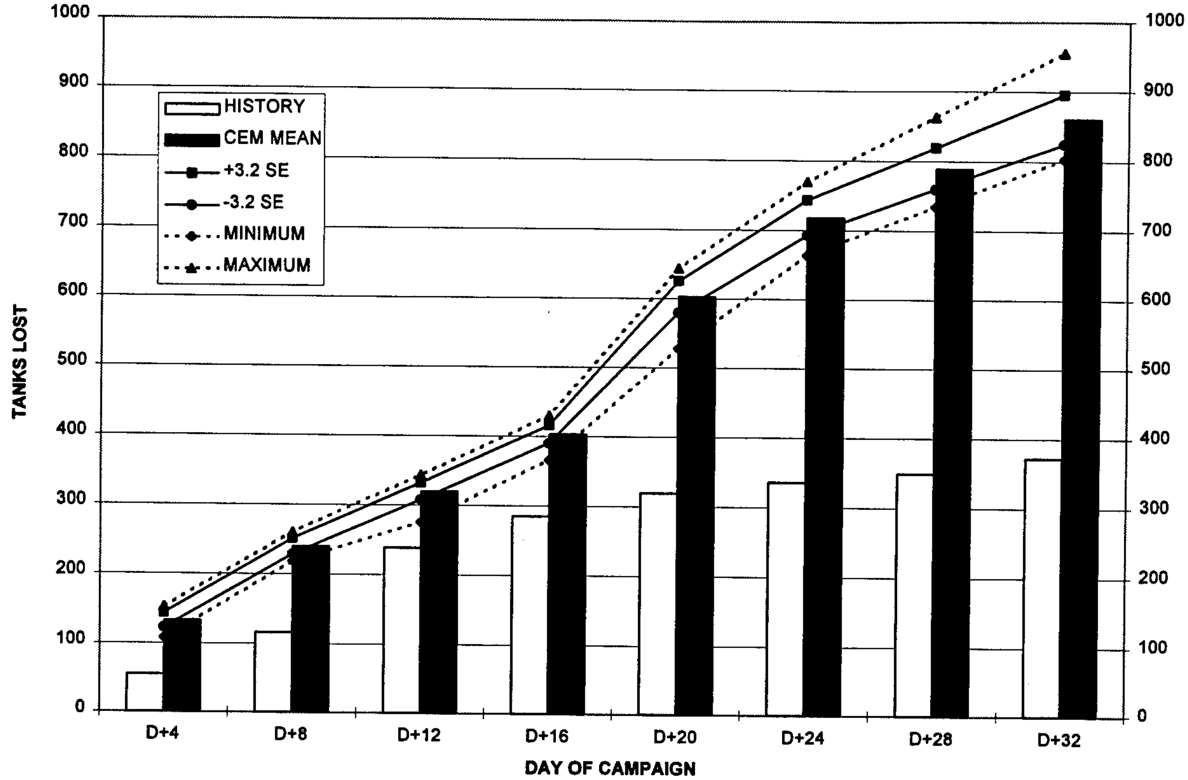


Figure G-5. Cumulative German Tank Losses (History vs STOCEM excursion case)

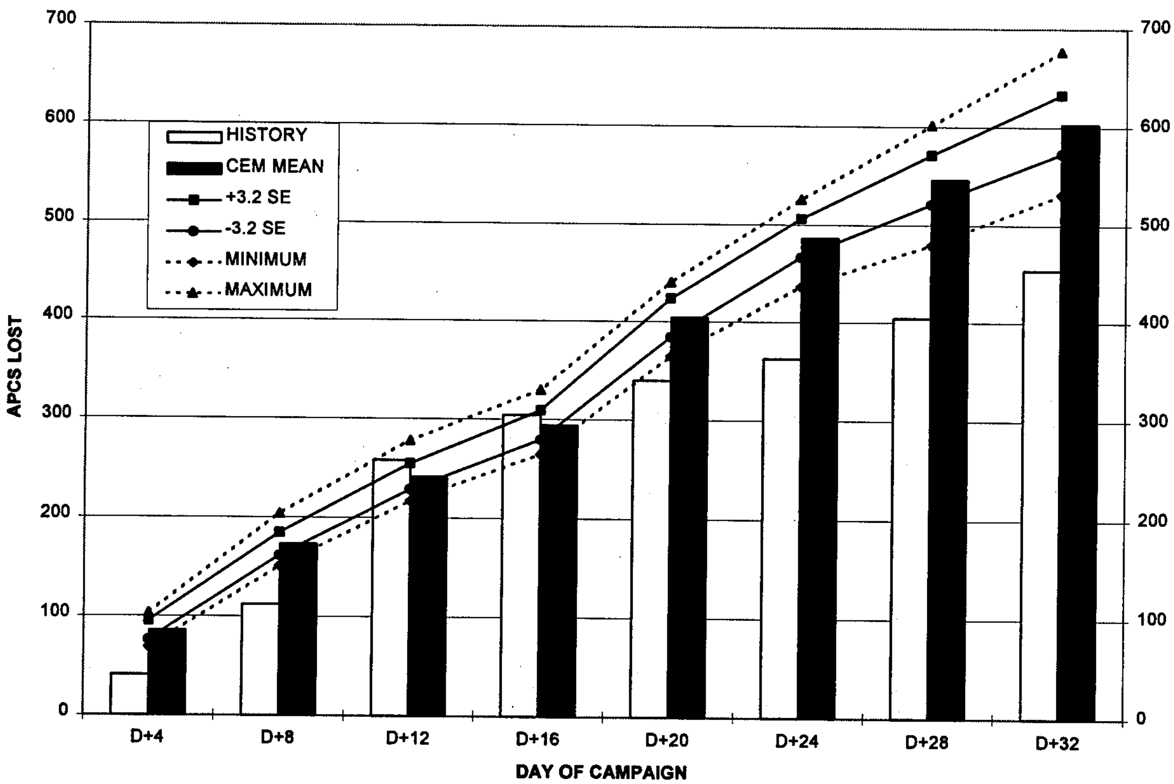


Figure G-6. Cumulative German APC Losses (History vs STOCEM excursion case)

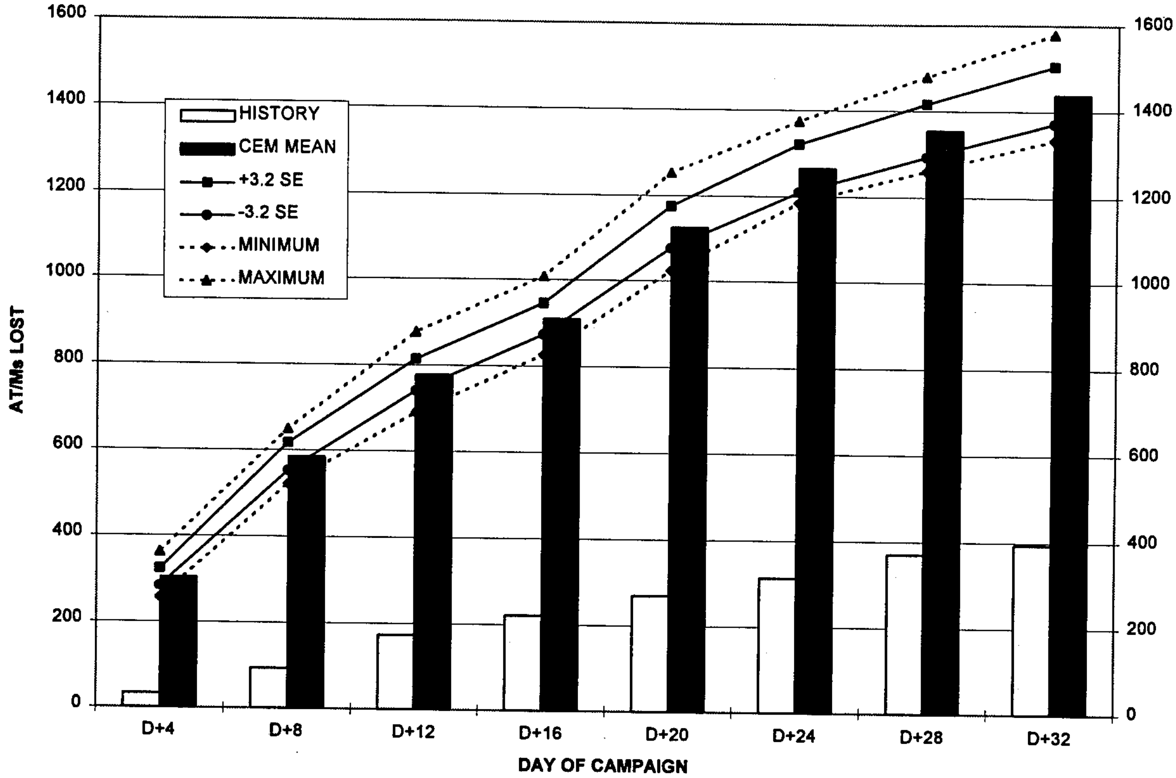


Figure G-7. Cumulative German AT/M Losses (History vs STOCEM excursion case)

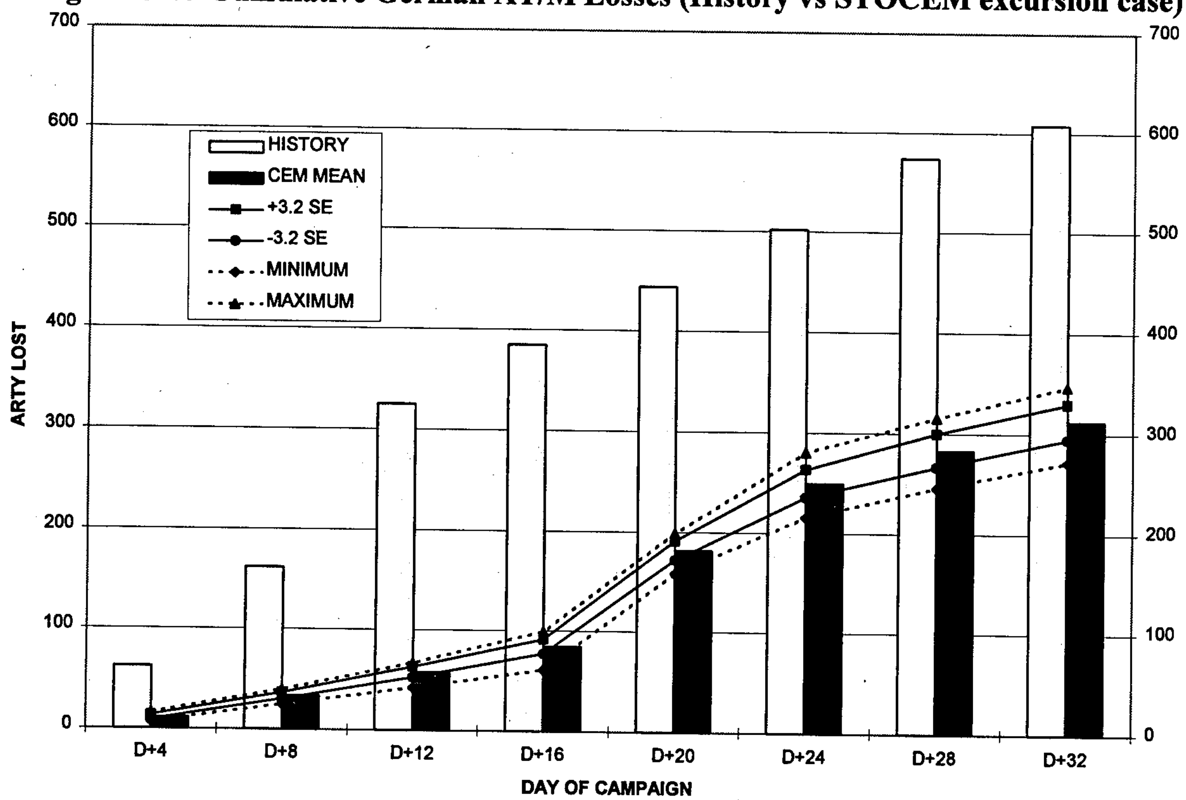


Figure G-8. Cumulative German Artillery Losses (History vs STOCEM excursion case)

G-3. LOSSES IN EACH 4-DAY PERIOD. Figures G-9 through G-12 show excursion case STOCEM and historical cumulative (since D-day) total US/UK weapon systems lost (destroyed or abandoned) during each 4-day period in the scenario. Figures G-13 through G-16 show analogous German loss results. Each chart shows, for STOCEM, the mean value, the max/min band, and the 99 percent/90 percent confidence limit band for losses of a specified type weapon system during each 4-day period.

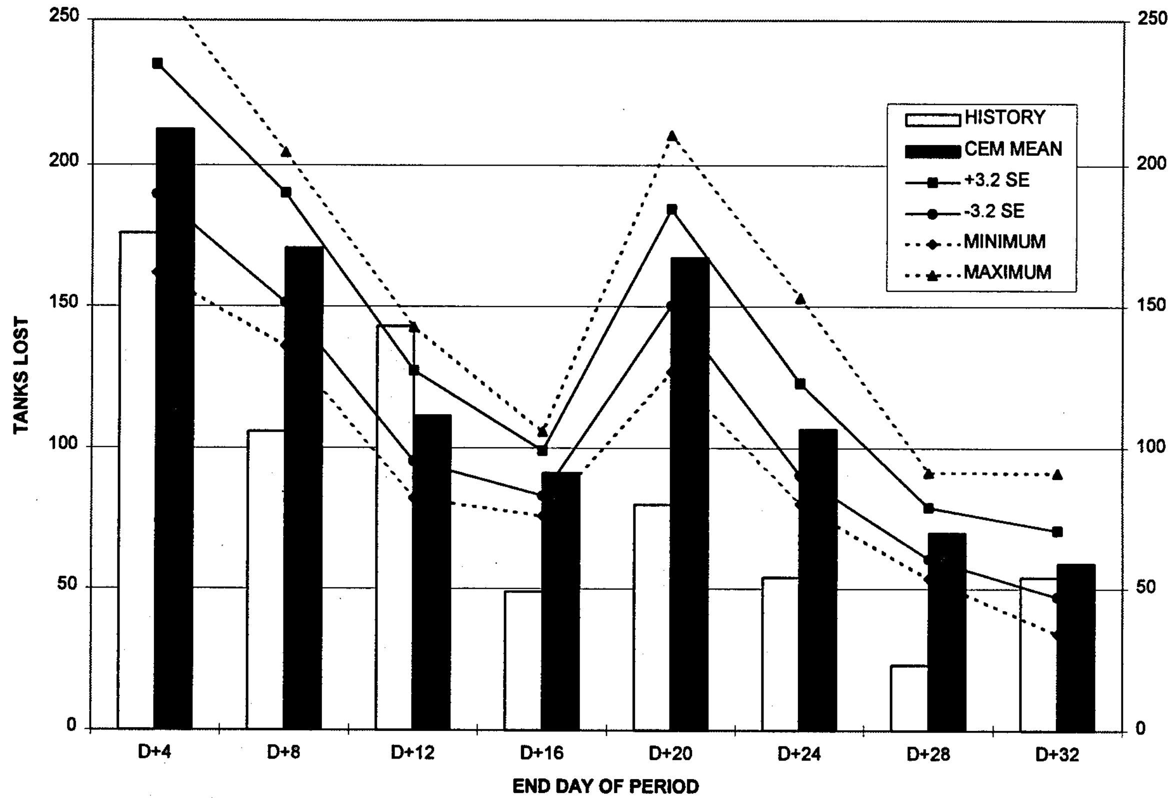


Figure G-9. US/UK Tank Losses in Each 4-day Period (History vs STOCEM excursion case)

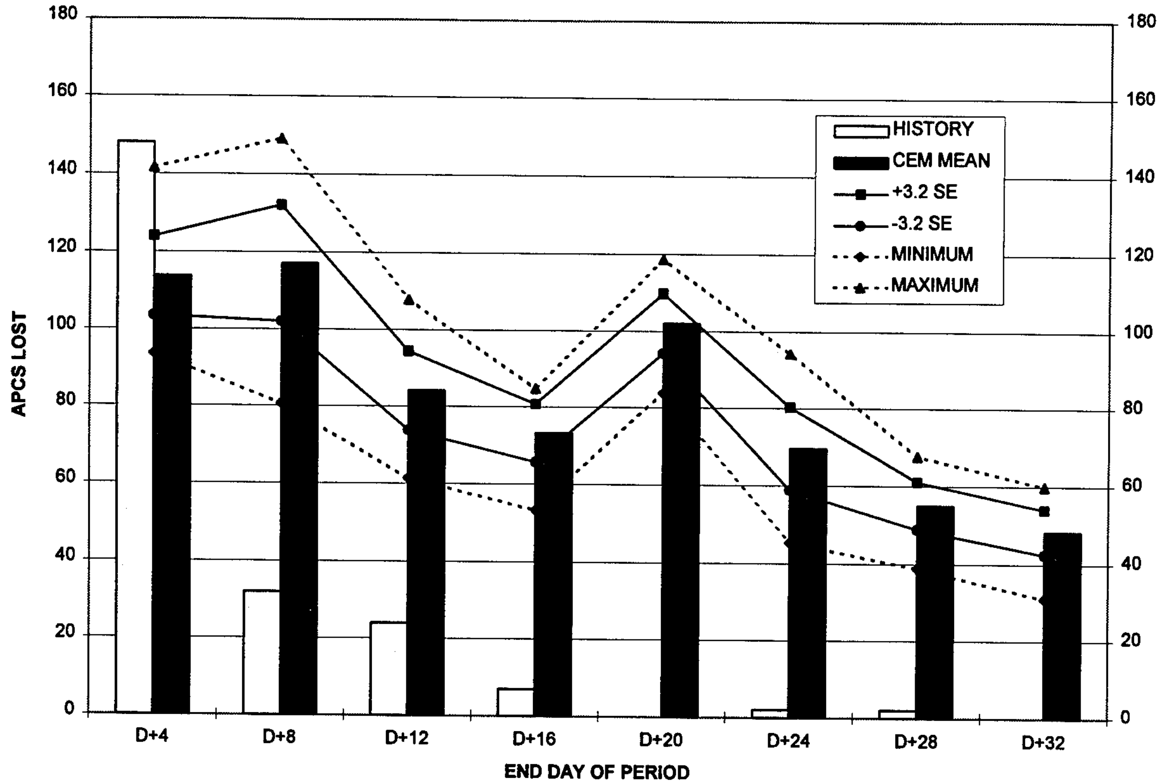


Figure G-10. US/UK APC Losses in Each 4-day Period (History vs STOCEM excursion case)

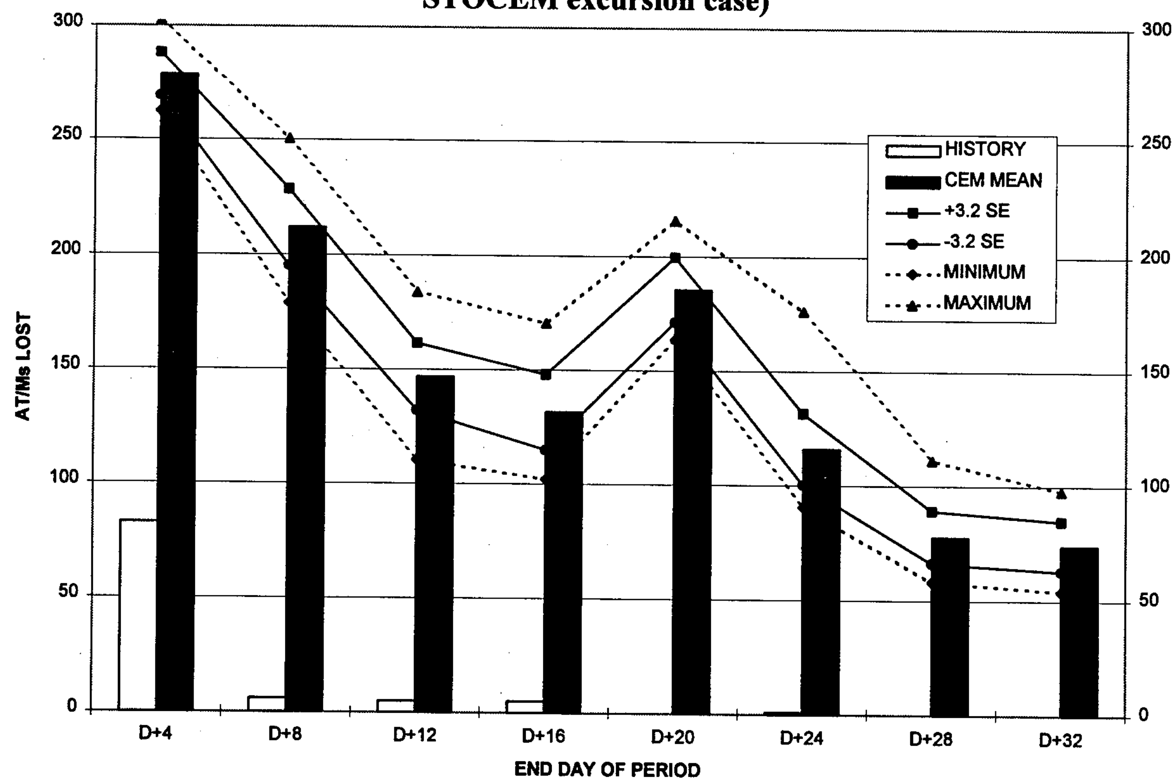


Figure G-11. US/UK AT/M Losses in Each 4-day Period (History vs STOCEM excursion case)

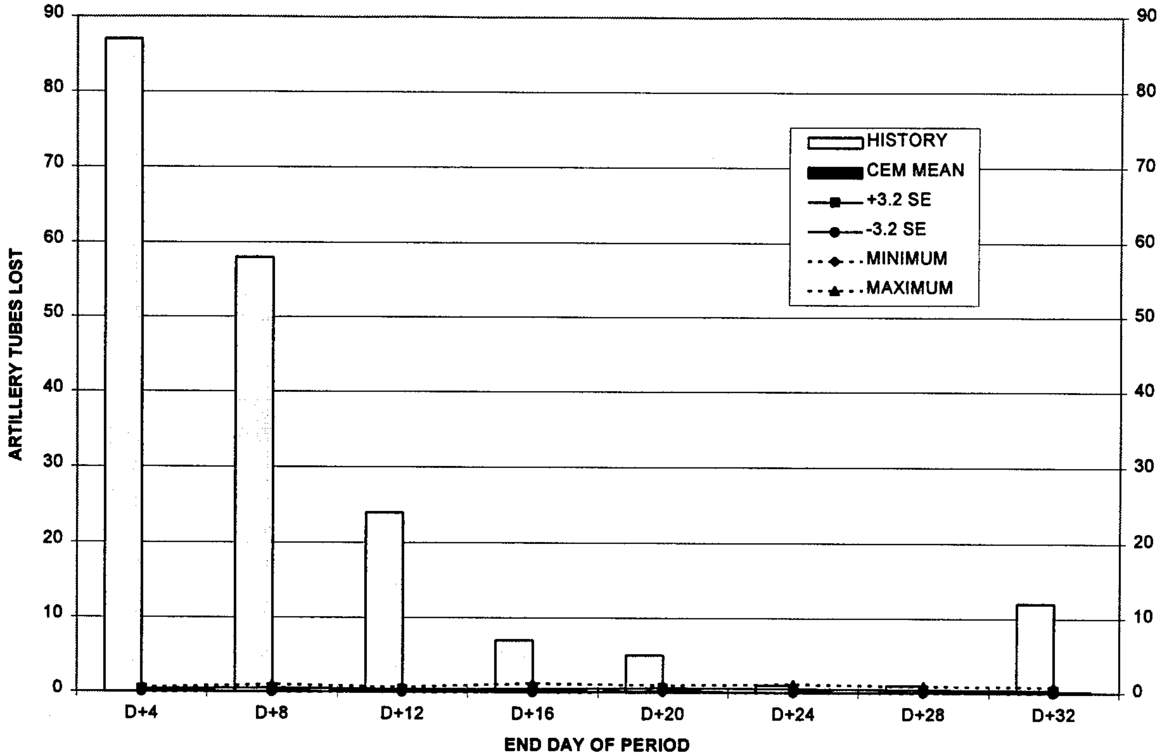


Figure G-12. US/UK Artillery Losses in Each 4-day Period (History vs STOCEM excursion case)

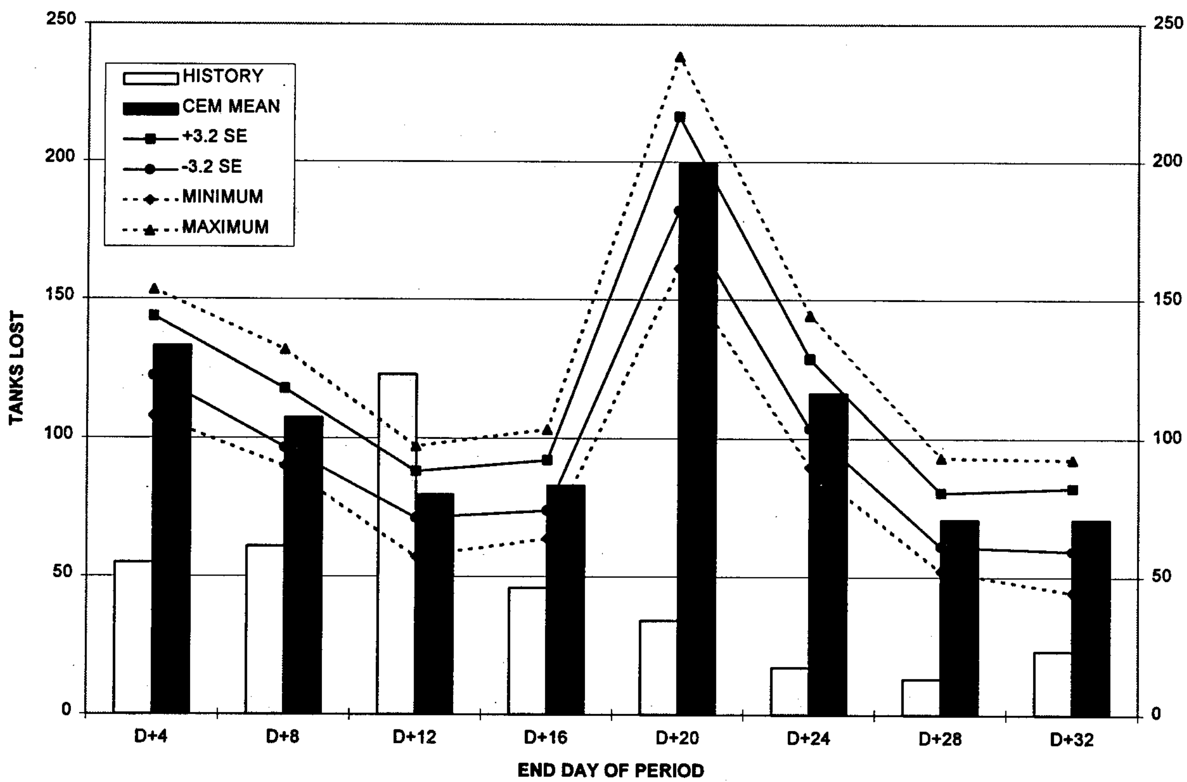


Figure G-13. German Tank Losses in Each 4-day Period (History vs STOCEM excursion case)

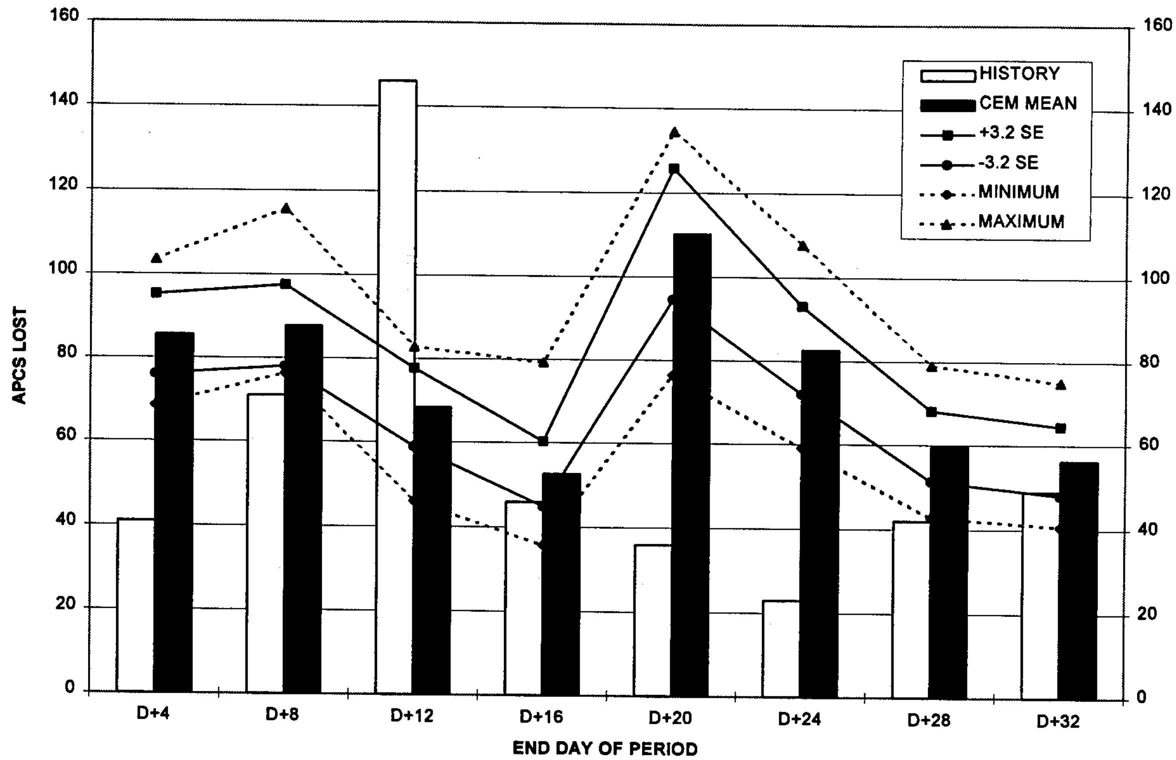


Figure G-14. German APC Losses in Each 4-day Period (History vs STOCEM excursion case)

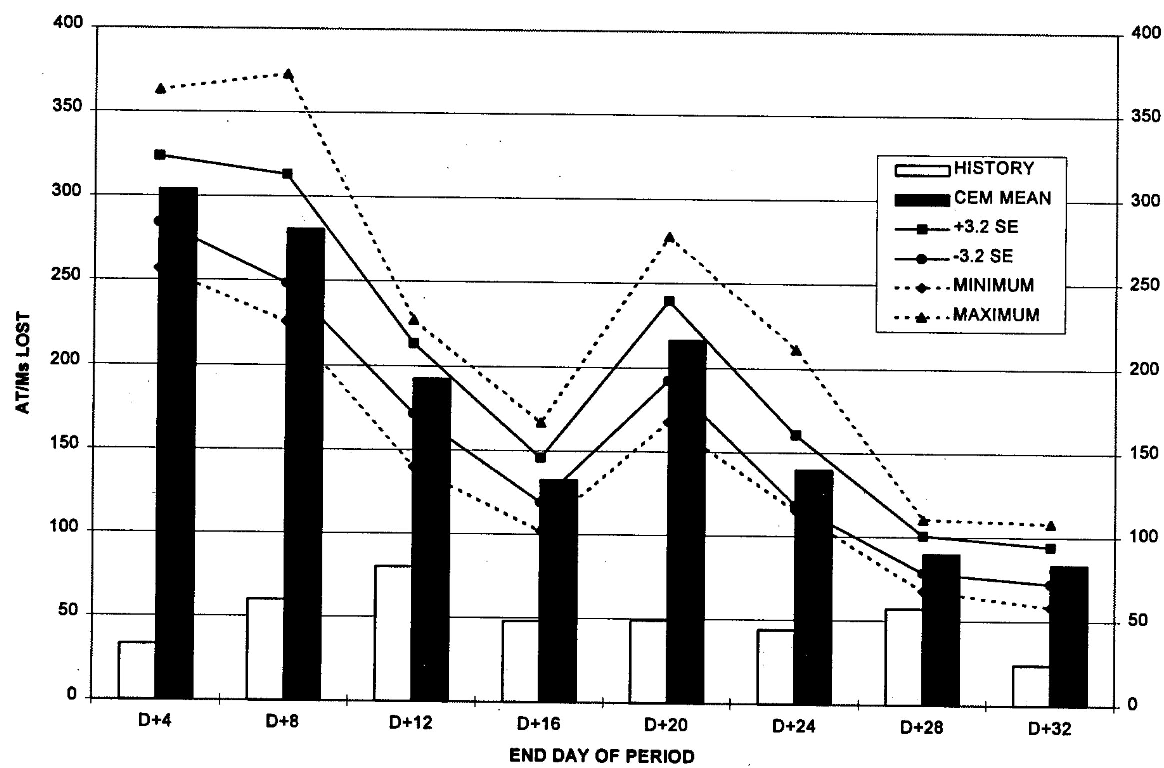


Figure G-15. German AT/M Losses in Each 4-day Period (History vs STOCEM excursion case)

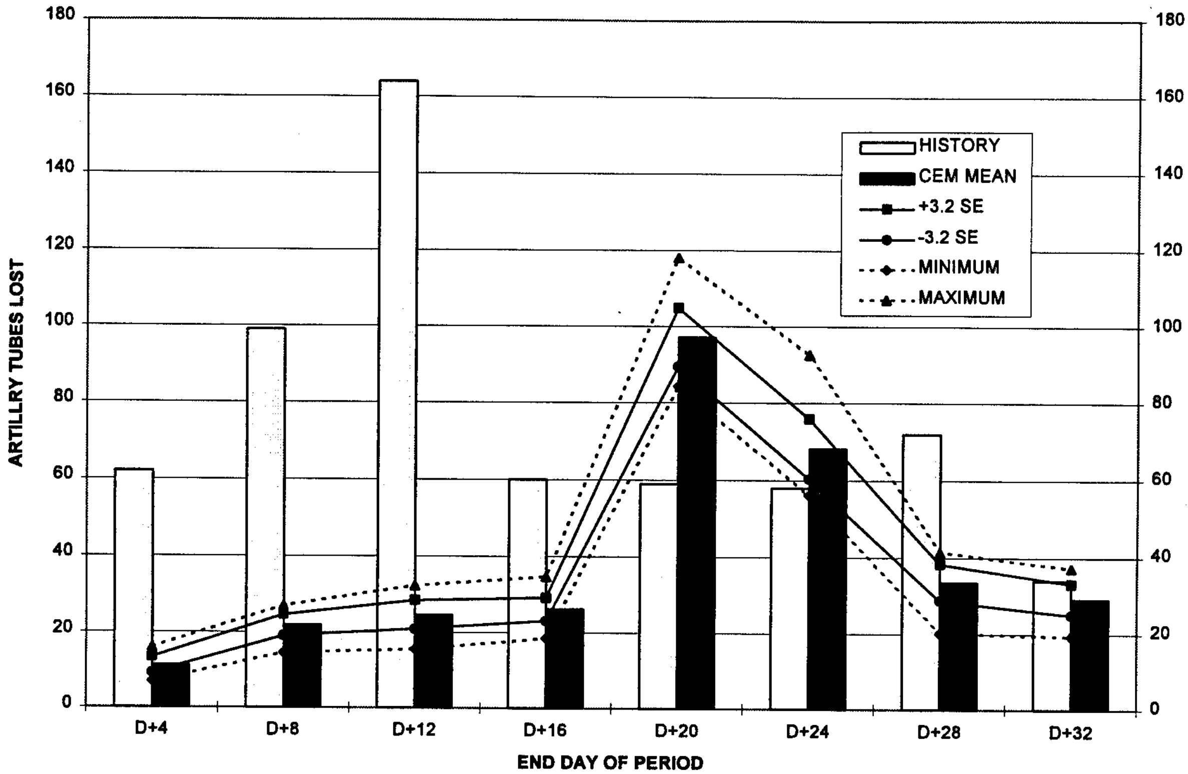


Figure G-16. German Artillery Losses in Each 4-day Period (History vs STOCEM excursion case)

G-4. COMPARISON OF STOCEM BASE CASE WITH STOCEM EXCURSION CASE. Figures G-17 through G-20 compare cumulative base case STOCEM losses with cumulative excursion case STOCEM losses for US/UK weapon systems. Figures G-21 through G-24 show analogous German loss results. Only mean (average) losses are shown.

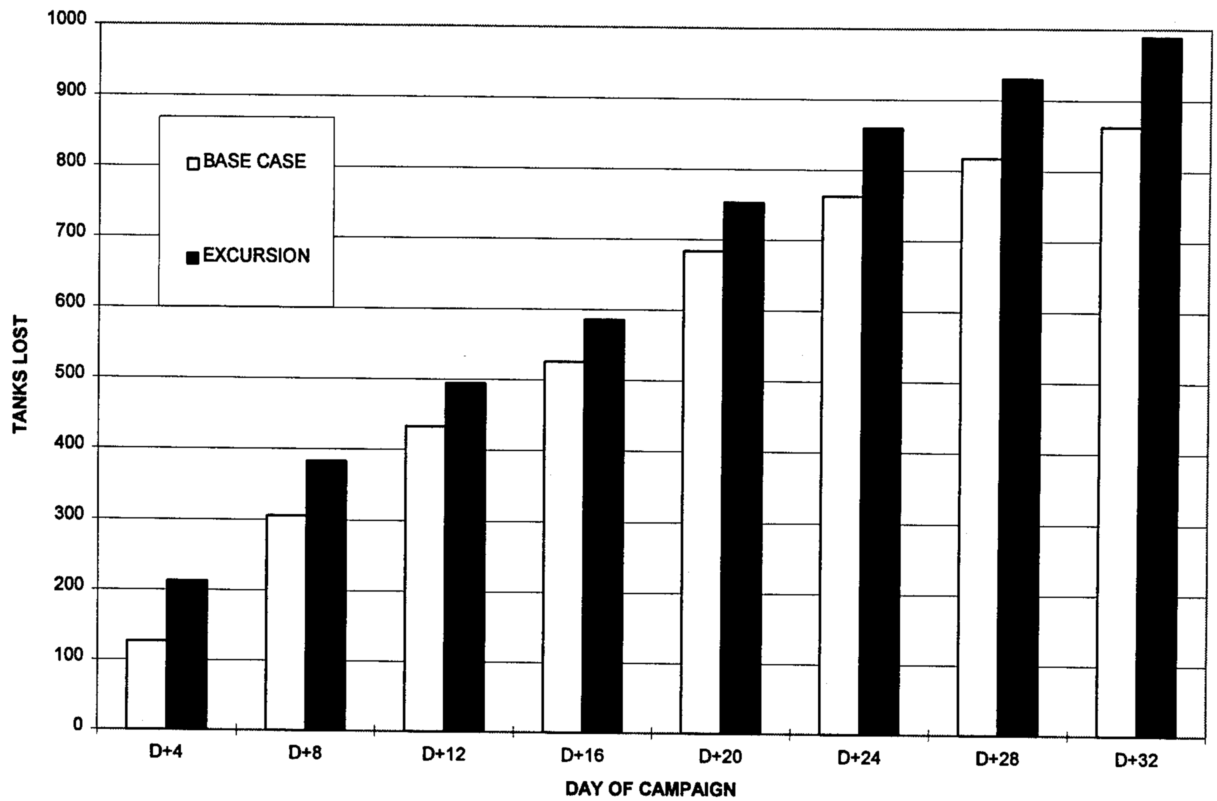


Figure G-17. Cumulative STOCEM US/UK Tank Losses (base case vs excursion case)

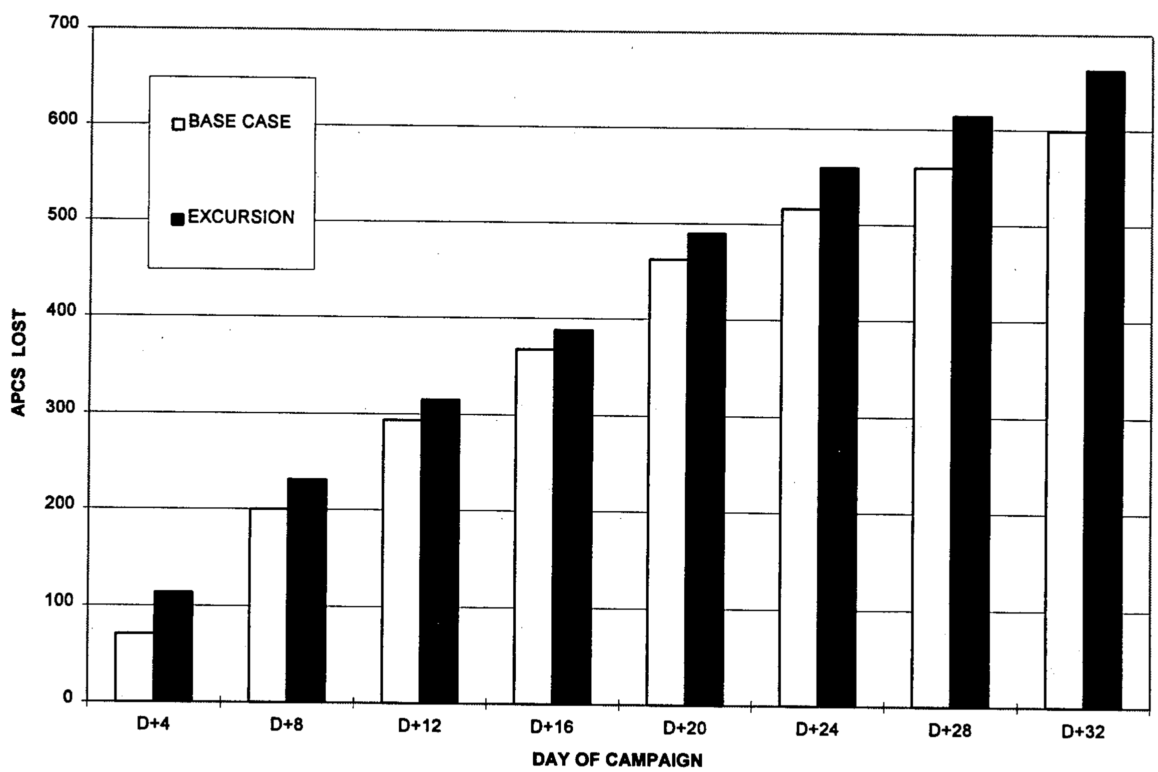


Figure G-18. Cumulative STOCEM US/UK APC Losses (base case vs excursion case)

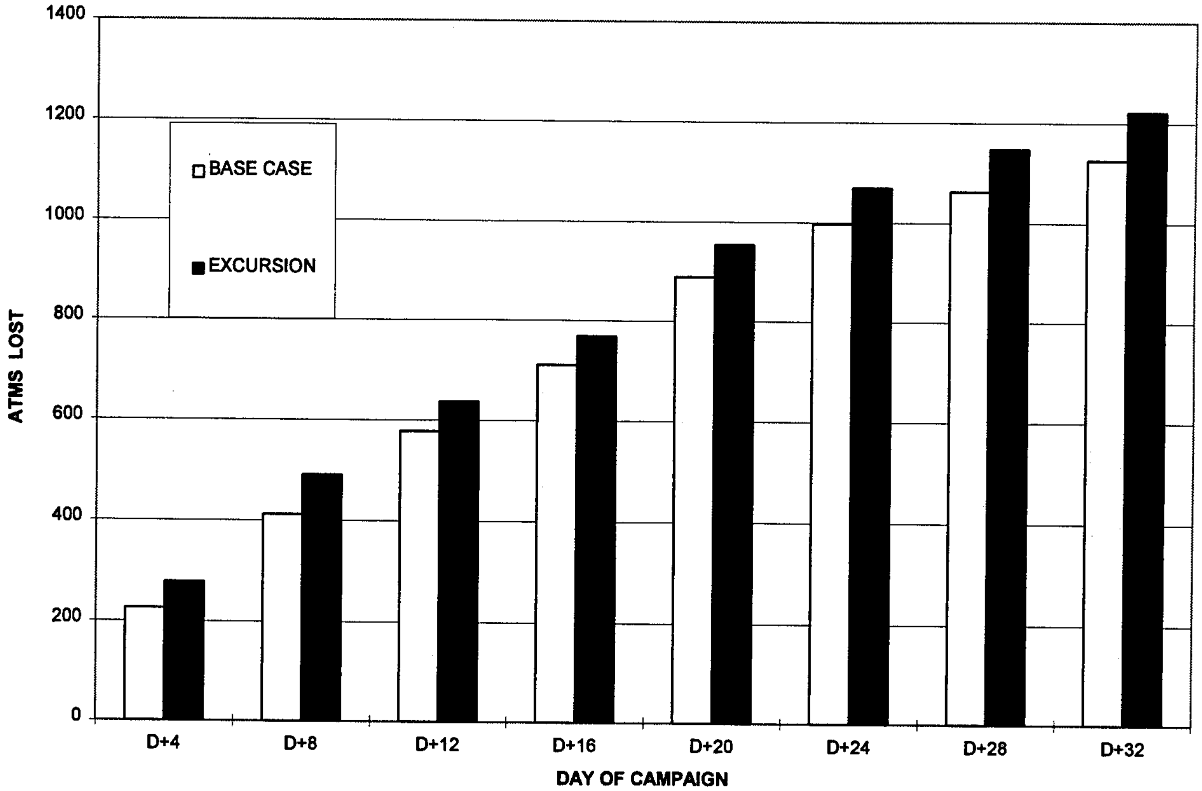


Figure G-19. Cumulative STOCEM US/UK AT/M Losses (base case vs excursion case)

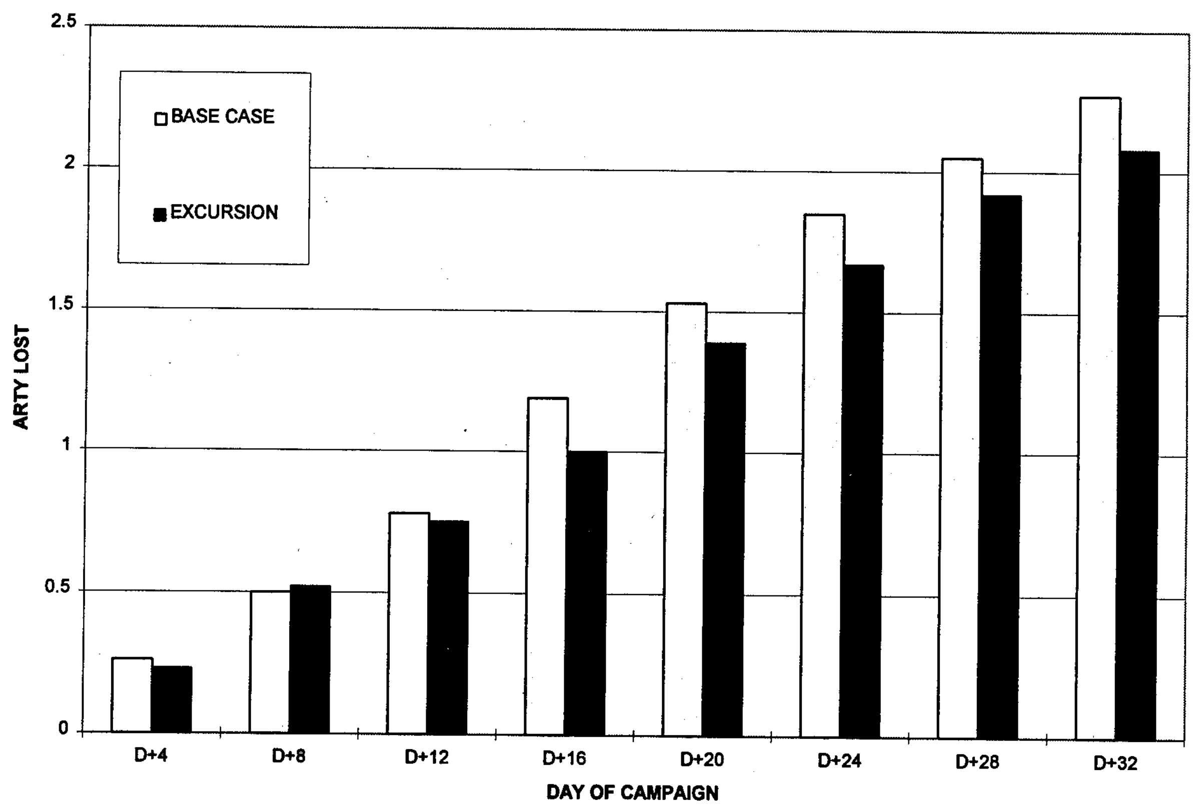


Figure G-20. Cumulative STOCEM US/UK Artillery Losses (base case vs excursion case)

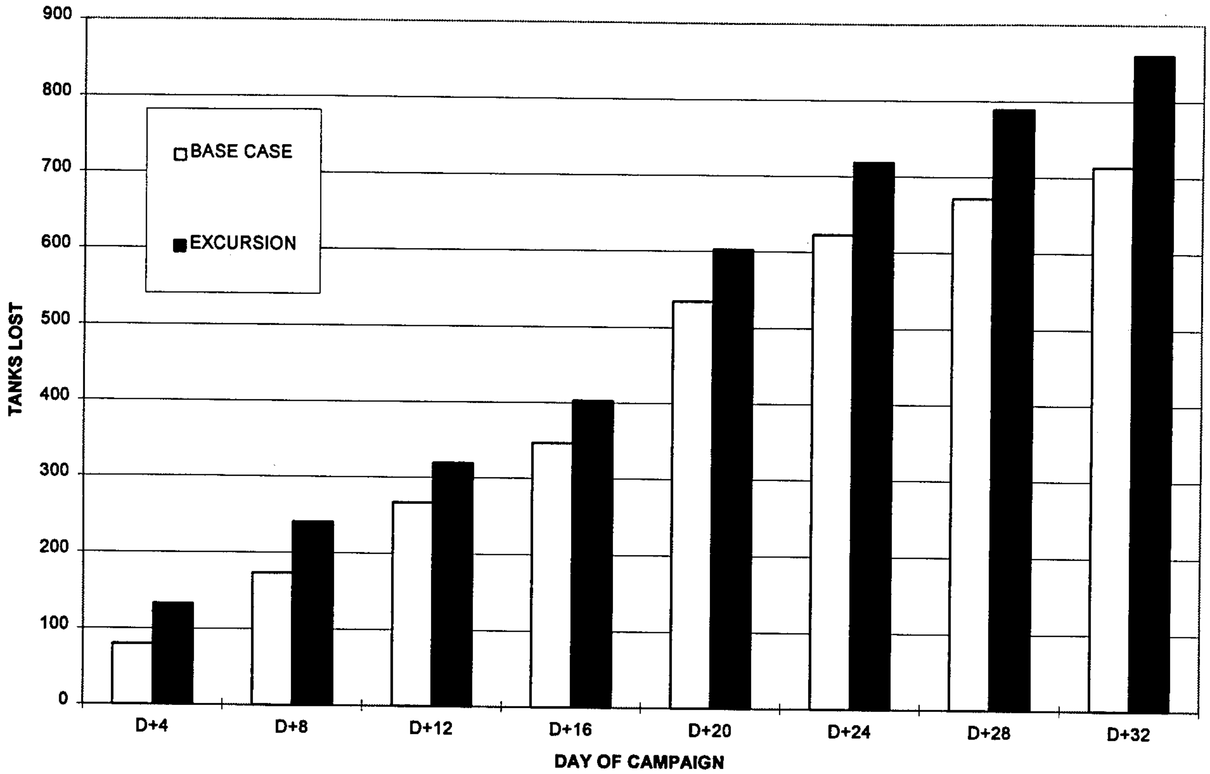


Figure G-21. Cumulative STOCEM German Tank Losses (base case vs excursion case)

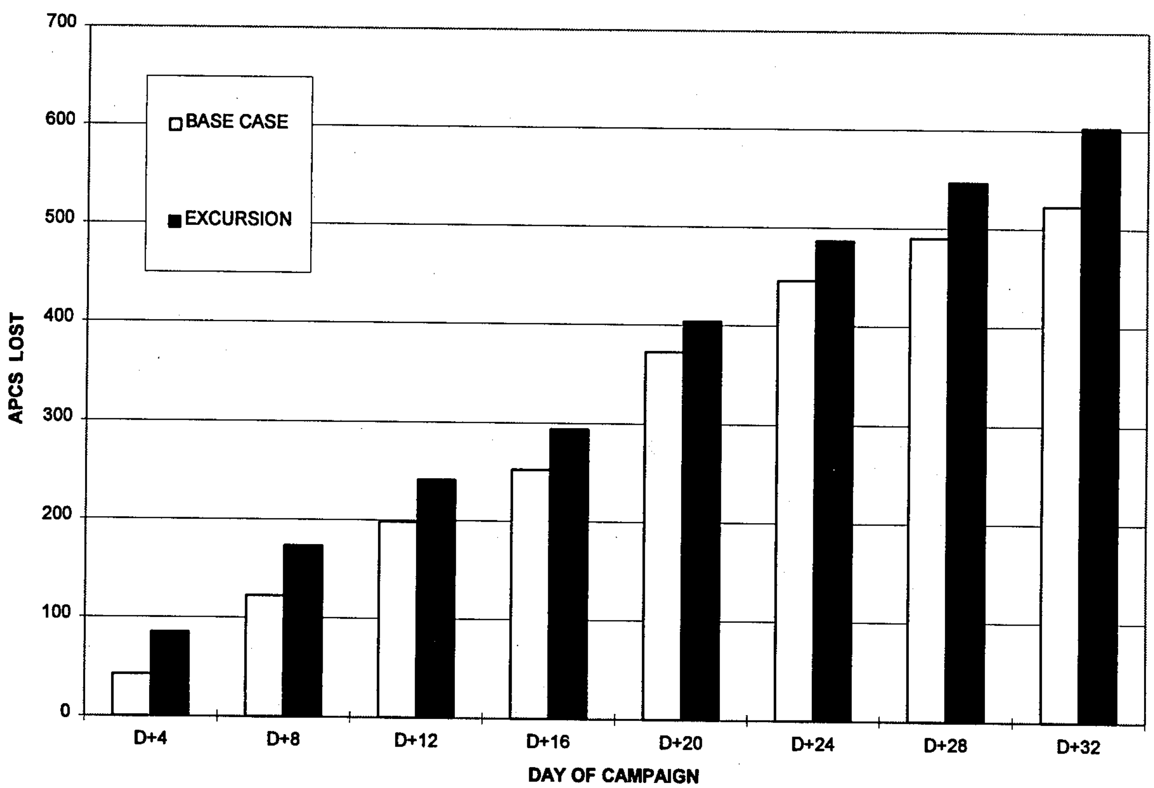


Figure G-22. Cumulative STOCEM German APC Losses (base case vs excursion case)

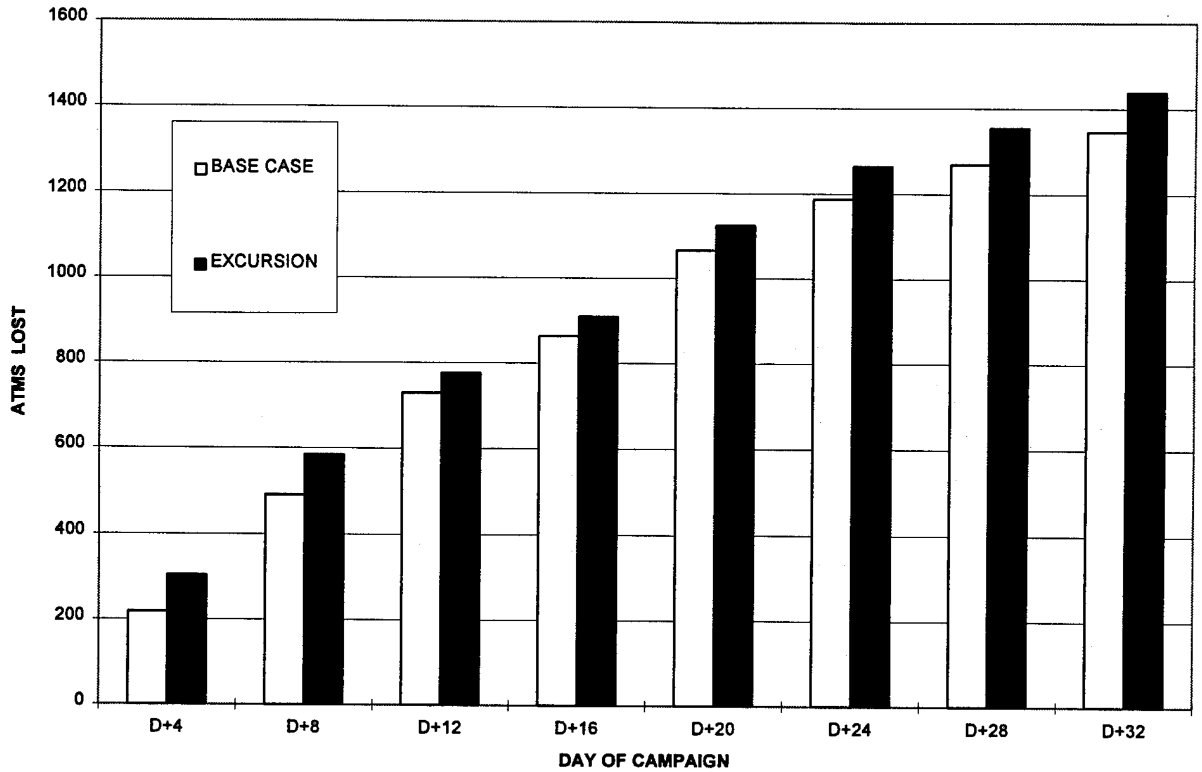


Figure G-23. Cumulative STOCEM German AT/M Losses (base case vs excursion case)

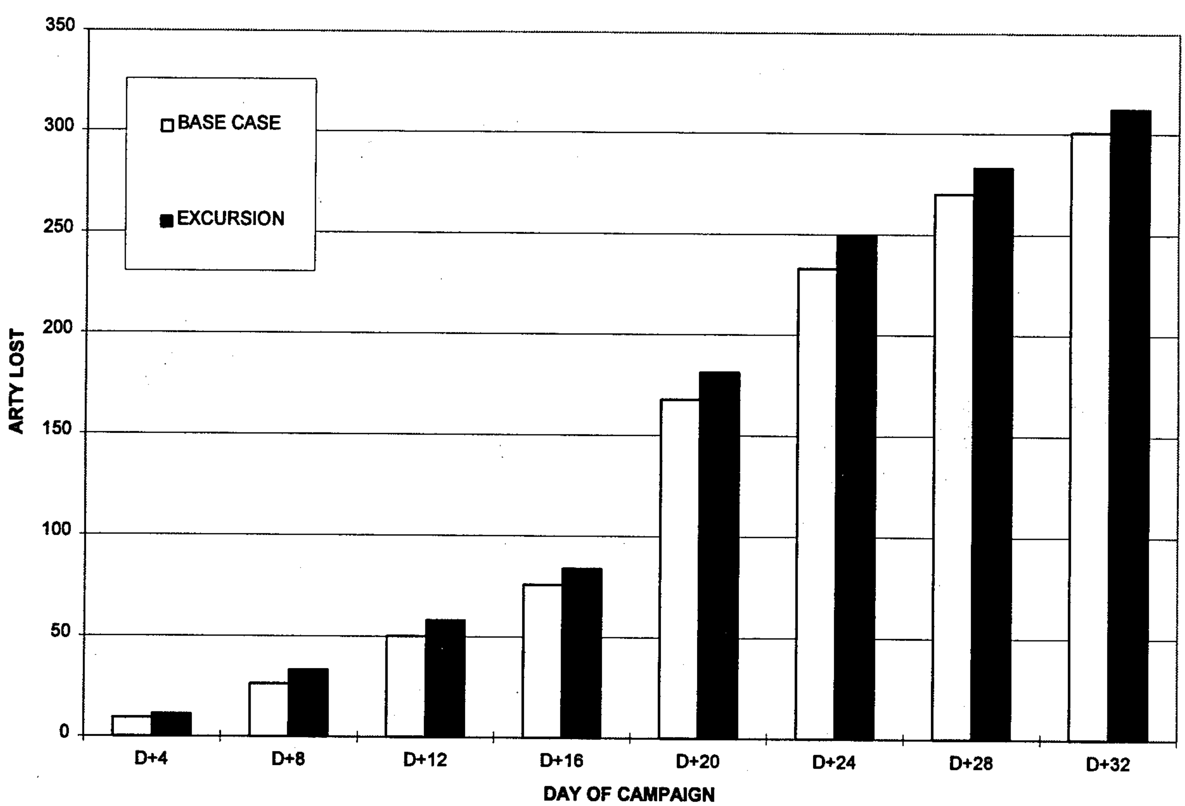


Figure G-24. Cumulative STOCEM German Artillery Losses (base case vs excursion case)

G-5. OVERVIEW COMPARISON ACROSS WEAPON SYSTEM CLASSES. Figures G-25 and G-26 show the ratio of excursion case STOCEM results to historical results for the cumulative STOCEM mean weapon system losses which are shown in Figures G-1 through G-8. Figures G-25 and G-26 are the STOCEM excursion case counterparts of the STOCEM base case results depicted in Figures 5-17 and 5-20. The fraction overestimation by STOCEM is reflected in the quantity: [1.00 - displayed ratio]. The US/UK artillery ratio is essentially zero throughout the figure. Figures G-27 and G-28 show the fraction of all excursion case STOCEM mean losses which occur in each 4-day period of the campaign. (These fractions, for any single weapon class, must sum to 1.00 over the entire campaign.) Figures G-27 and G-28 are the STOCEM excursion case counterparts of the STOCEM base case results depicted in Figures 5-18 and 5-21.

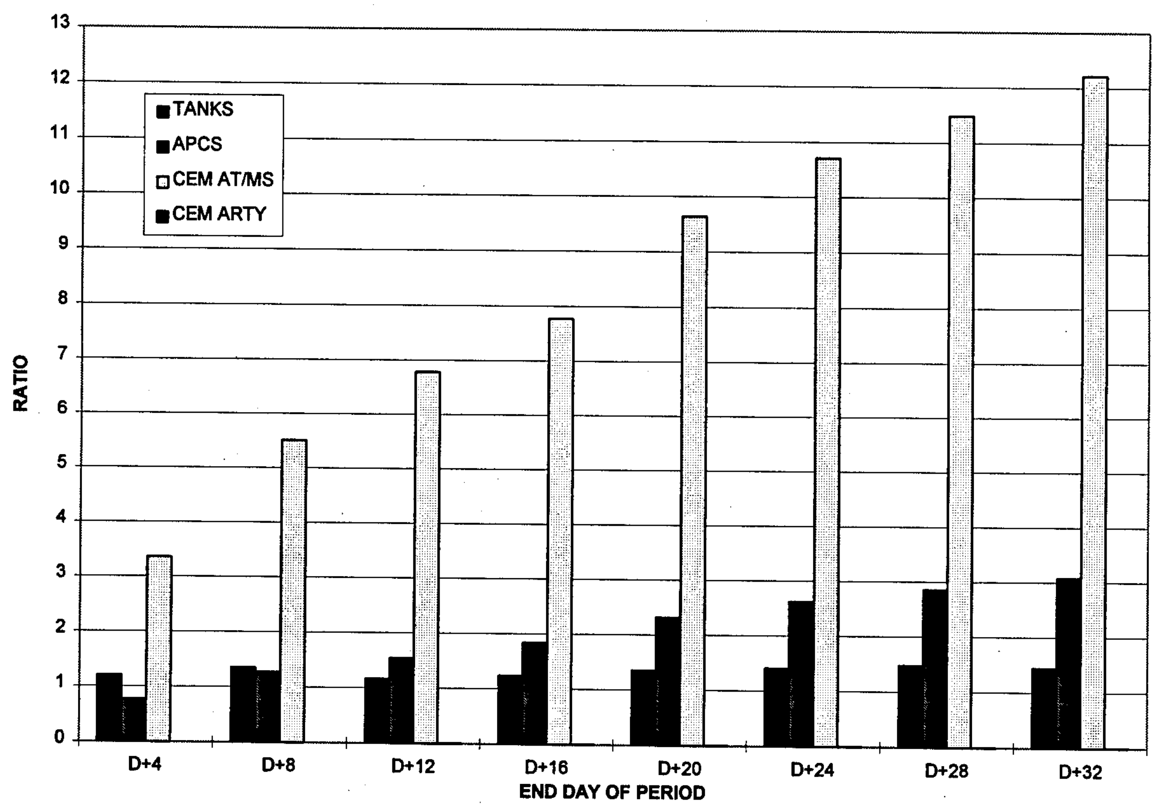


Figure G-25. Ratio of Cumulative STOCEM US/UK Losses to Cumulative Historical Losses (STOCEM excursion case)

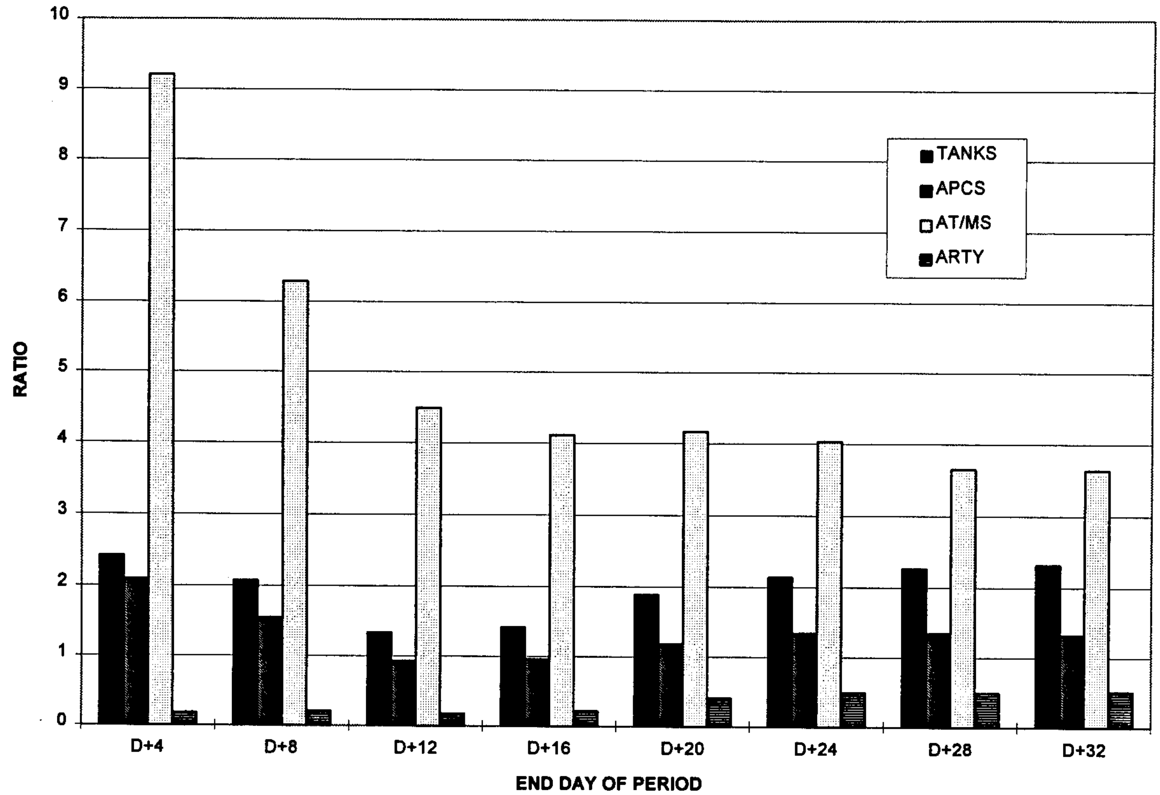


Figure G-26. Ratio of Cumulative STOCEM German Losses to Cumulative Historical Losses (excursion case)

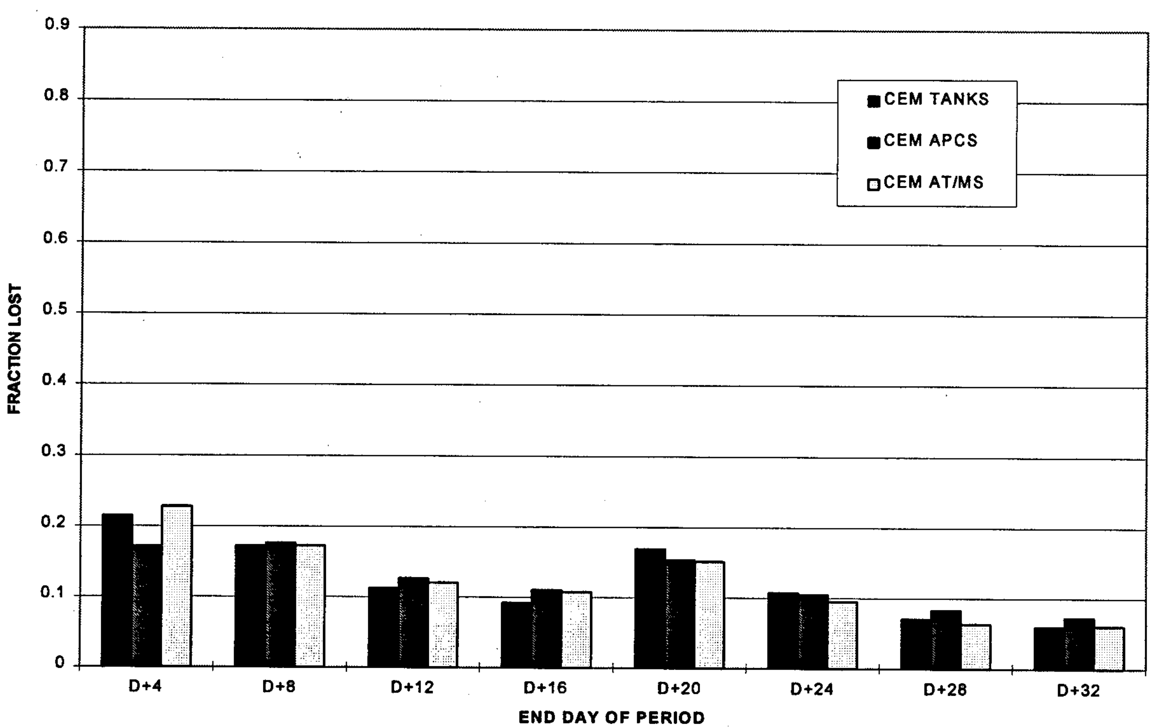


Figure G-27. Fraction of Total STOCEM US/UK Losses in Each 4-day period (STOCEM excursion case)

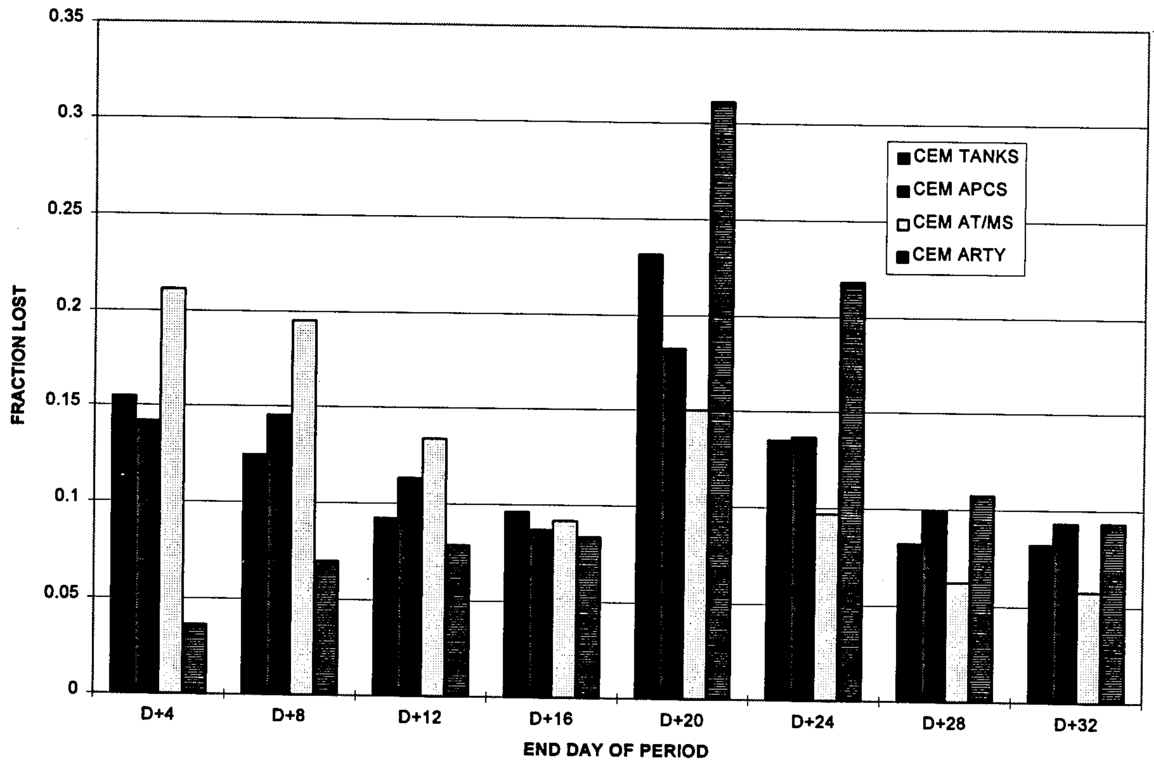


Figure G-28. Fraction of Total STOCEM German Losses Generated in Each 4-day Period (STOCEM excursion case)

APPENDIX H

COMPARATIVE PERSONNEL CASUALTY RESULTS

H-1. OVERVIEW. This appendix supplements and amplifies Chapter 6 of the report. Figures portray and compare the simulated and historical personnel casualties and casualty rates, primarily for the US/UK force, during the course of the Ardennes Campaign. The figures include only casualties in the line units available for commitment to the campaign in the ARCAS scenario, as reflected in Table 2-2. Casualty results are further partitioned into four category types for the US/UK force. Casualty types include KIA, CMIA, WIA, and DNBI. The KIA and CMIA are sometimes combined into a "killed or captured/missing in action" casualty type denoted as KCMIA. Daily casualty rates and fraction of total casualties in each category type during the campaign are shown for every other (second) day in the scenario for the US/UK force. This appendix also defines a category denoted as "permanent casualties," which consists of only those casualties which never return to duty during the campaign. Measures of stochastic uncertainty in STOCEM results, based on statistical sampling theory, are also shown on most charts. The groups of figures in this appendix, in the order of presentation, include:

a. Comparative (history vs STOCEM base case) daily casualties for each casualty type and for selected combinations of casualty types.

b. Comparative (history vs STOCEM excursion case) daily casualties for each casualty type and for selected combinations of casualty types.

c. Comparative (history vs STOCEM base case) daily casualty rates for each casualty type and for selected combinations of casualty types.

d. Comparative (history vs STOCEM excursion case) daily casualty rates for each casualty type and for selected combinations of casualty types.

e. Comparative (history vs STOCEM base case) proportions of total casualties in each casualty type.

f. Comparative (history vs STOCEM excursion case) proportions of total casualties in each casualty type.

g. Comparative (history vs STOCEM base case) daily permanent casualties for each casualty type and for selected combinations of casualty types.

h. Comparative (history vs STOCEM excursion case) daily permanent casualties for each casualty type and for selected combinations of casualty types.

i. Comparative (history vs STOCEM base case) daily permanent casualty rates for each casualty type and for selected combinations of casualty types.

j. Comparative (history vs STOCEM excursion case) daily permanent casualty rates for each casualty type and for selected combinations of casualty types.

k. Comparison of STOCEM base case total casualties with STOCEM excursion case total casualties.

l. Comparative (history vs STOCEM base case) cumulative total US/UK personnel casualties, in each casualty type, at 4-day intervals, and comparative (history vs STOCEM base case) total US/UK personnel casualties in each casualty type during each 4-day period.

H-2. FORMAT AND STRUCTURE OF CHARTS. The formats of the figures are the same as used in Chapter 6. In addition to the STOCEM average value, most figures show the STOCEM maximum and minimum over the 16 STOCEM replications, along with the 99 percent/90 percent confidence limits (denoted as +3.2 SE and -3.2 SE in the chart). These two pairs of lines form bands which graphically portray the uncertainty in stochastic variation in the STOCEM casualty results.

H-3. EXTRAPOLATION OF STOCEM RESULTS. STOCEM explicitly simulates only the infantry personnel, artillery personnel, and weapon crews in front-line units. The ACSDB casualty records are more comprehensive and describe casualties for all personnel in units. For consistency, the base population for casualty assessment was the set of all line units available for commitment to the campaign at the time of assessment, as represented in Table 2-2. This necessitated extrapolating both STOCEM casualties and STOCEM onhand personnel from only infantry/artillery personnel to all personnel in the line units. The following procedures were used to do these extrapolations.

a. Casualties. STOCEM casualties, reflecting only infantry/artillery/crew casualties, were multiplied by 1.105 to extrapolate to casualties over all military personnel specialties in the STOCEM scenario force. This multiplier (1.105) is a factor, derived from history and experience, which has been used during casualty stratification in other CEM applications at CAA.

b. Onhand Personnel. A direct assessment of all personnel in the campaign was unavailable from STOCEM, since the simulation tracked only the infantry/artillery/crew personnel. However, as noted in Chapter 6, total STOCEM US/UK casualties were close to the historical casualties. Therefore, the STOCEM onhand personnel for the scenario force on a given day was assumed equal to the historical ACSDB onhand personnel for the scenario force on that day. This is only an approximation, since STOCEM casualties differed from historical casualties. The onhand personnel total is used only to compute casualty rates.

H-4. ESTIMATION OF HISTORICAL PERMANENT CASUALTIES. STOCEM simulates a casualty category called " permanent casualties" which consists of only those casualties which never return to duty during the campaign. These permanent casualties are usually evacuated from the theater. Those casualties which return to duty in STOCEM are called "temporary casualties." Thus, total STOCEM casualties is the sum of permanent and temporary casualties. This subcategorization applies only to WIA and DNBI because all KIA and CMIA are permanent casualties. Since the ACSDB did not classify casualties according to whether they returned to theater, a method was devised to approximately estimate the historical permanent WIA and DNBI from the ACSDB. The approach used was, for the ACSDB casualty data for a day, to subtract the recorded personnel returns from the (combined) WIA and DNBI for the day in proportions reflecting historical experience. Specifically, in the ACSDB casualty record for a day:

a. Compute estimated temporary WIA as (.17)(WIA), where WIA is the ACSDB entry. This is based on the history-based casualty stratification factors used by CAA which characterize the fraction of total WIA which are kept in theater and will return to duty.

b. Compute estimated temporary DNBI as (.62)(DNBI), where DNBI is the ACSDB entry. This is based on the history-based casualty stratification factors used by CAA which characterize the fraction of total DNBI which are kept in theater and will return to duty.

c. Partition total ACSDB personnel returns recorded for the day in the same proportions as the estimated temporary WIA and DNBI. Thus we have:

(1) Estimated WIA returns = (total ACSDB returns)(.17)(WIA)/SUM, where SUM = (.17)(WIA) + (.62)(DNBI).

(2) Estimated DNBI returns = (total ACSDB returns)(.62)(DNBI)/SUM, where SUM is defined above.

d. Compute (estimated) permanent ACSDB WIA = ACSDB WIA - estimated WIA returns.

e. Compute (estimated) permanent ACSDB DNBI = ACSDB DNBI - estimated DNBI returns.

The above estimate of permanent casualties in the ACSDB is applied only to enable a comparison with STOCEM permanent casualty results. These comparisons are shown in Figures H-40 through H-55. The "history" results in these charts are adjusted estimates computed in the above manner and should be considered much "softer" data than the directly recorded ACSDB statistics

H-5. BASE CASE DAILY CASUALTIES. Figures H-1 through H-7 compare historical daily casualties with STOCEM base case daily casualties for each casualty type and for selected combinations of casualty types. The figures include only casualties in the line units available for commitment to the campaign in the ARCAS scenario, as reflected in Table 2-2. The casualty types counted in the chart are identified in the title of each figure. Results are plotted for every second day of the campaign.

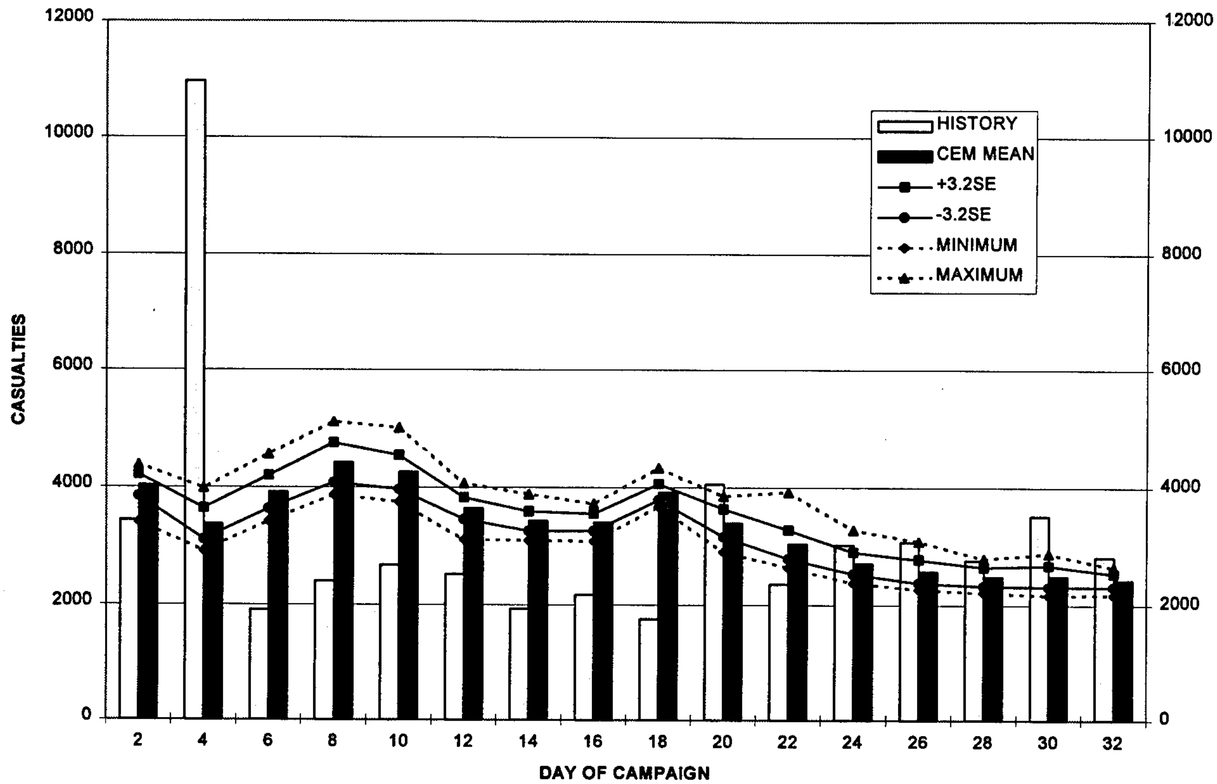


Figure H-1. US/UK Daily Casualties (base case): KCMIA + WIA and DNBI

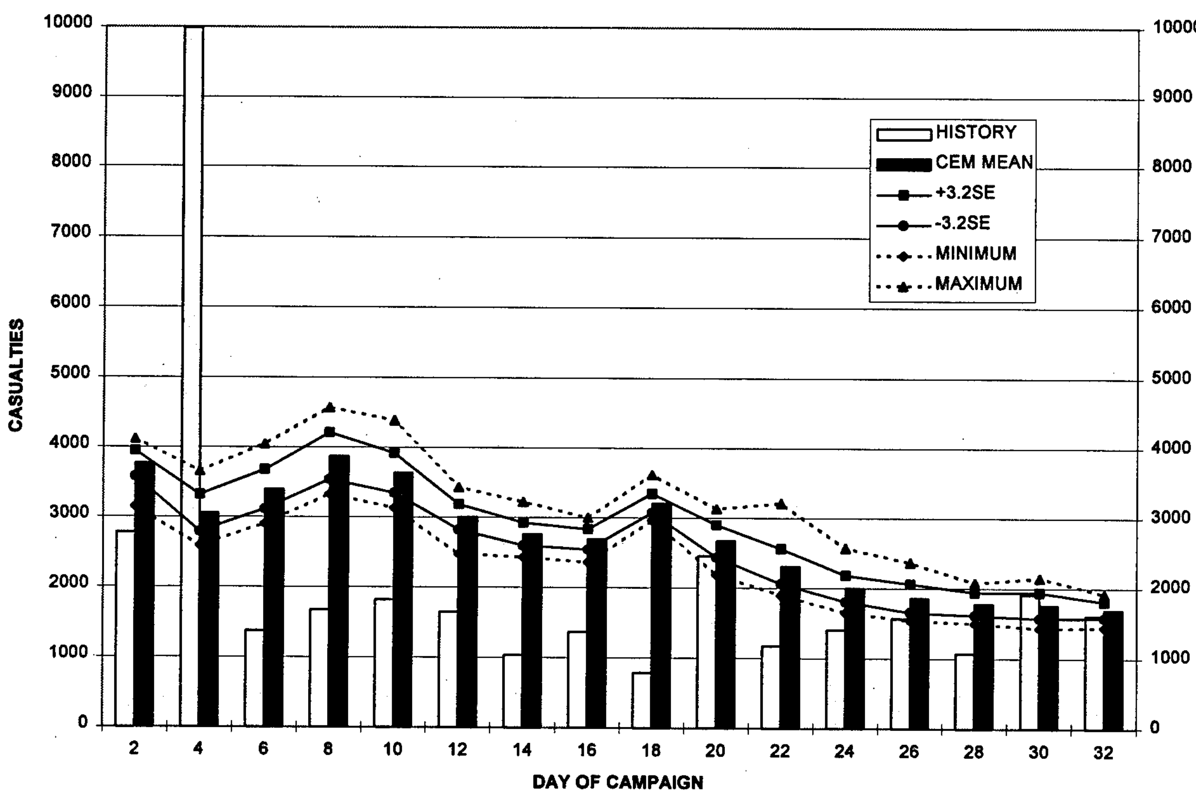


Figure H-2. US/UK Daily Combat Casualties (base case): KCMIA + WIA

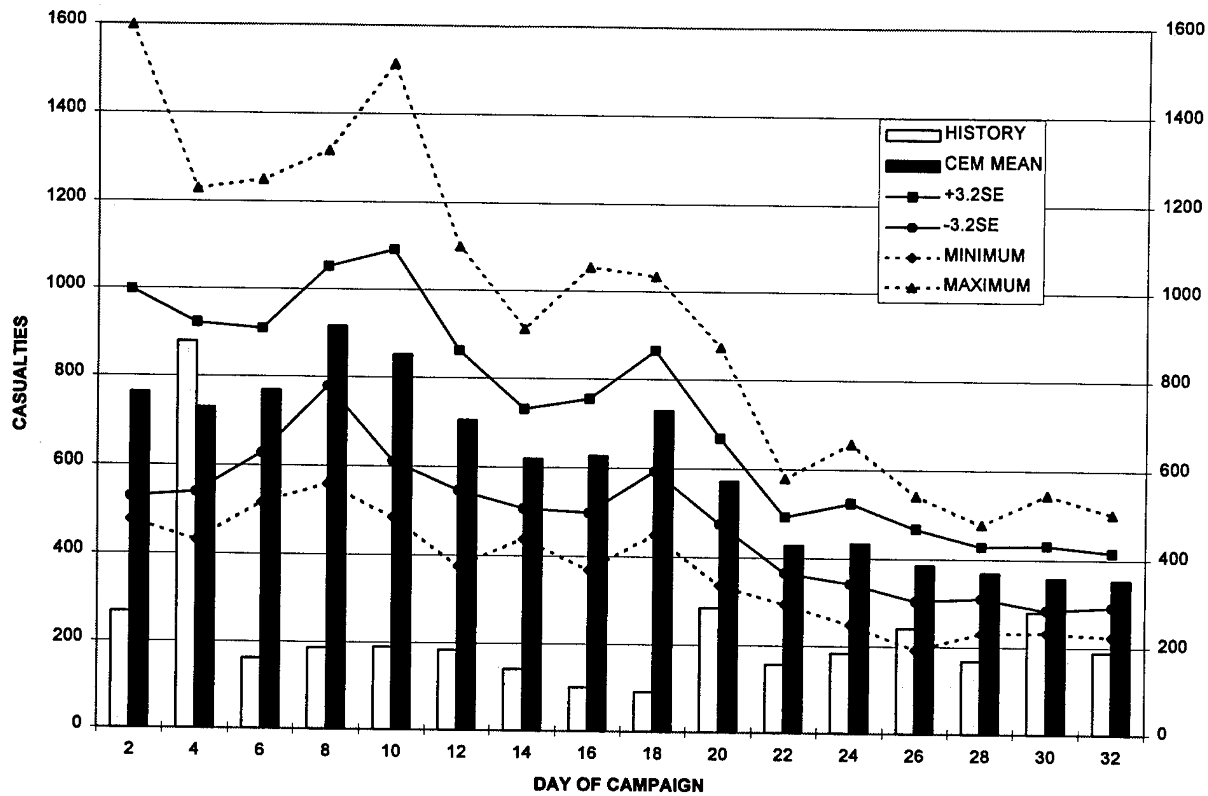


Figure H-3. US/UK Daily KIA (base case)

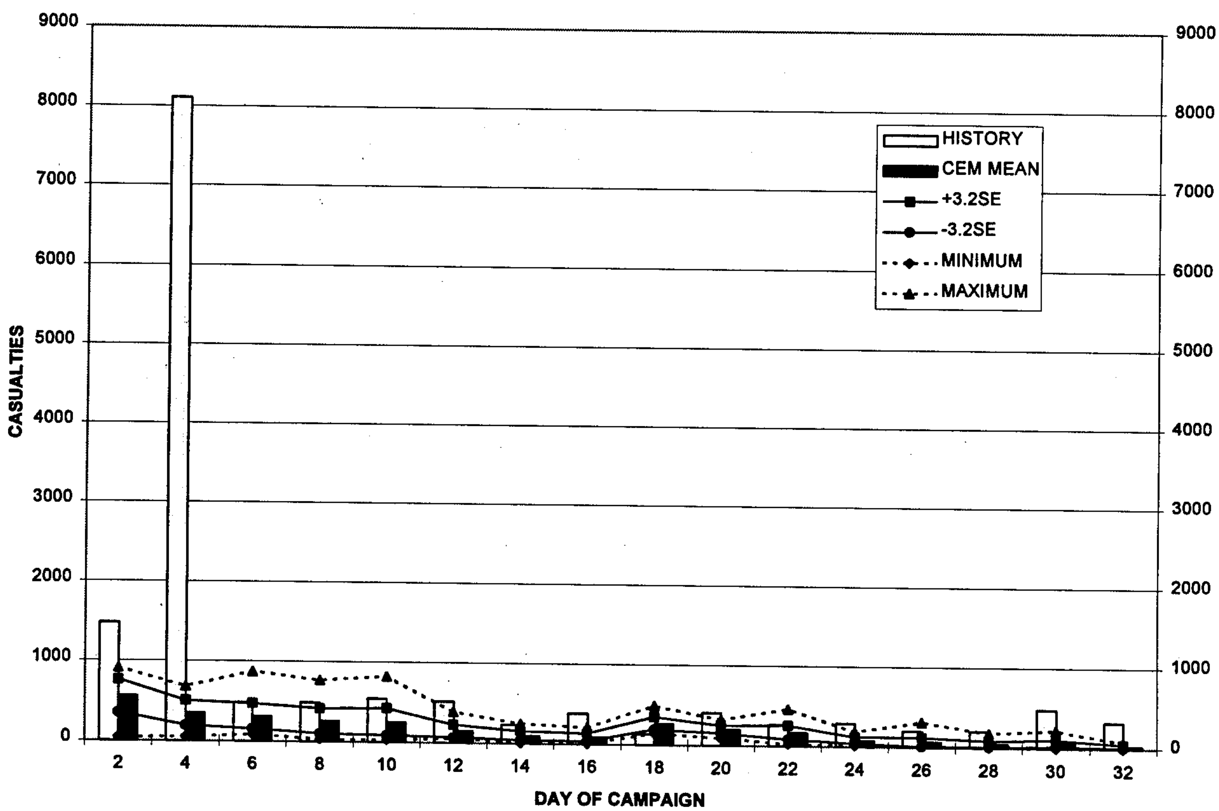


Figure H-4. US/UK Daily CMIA (base case)

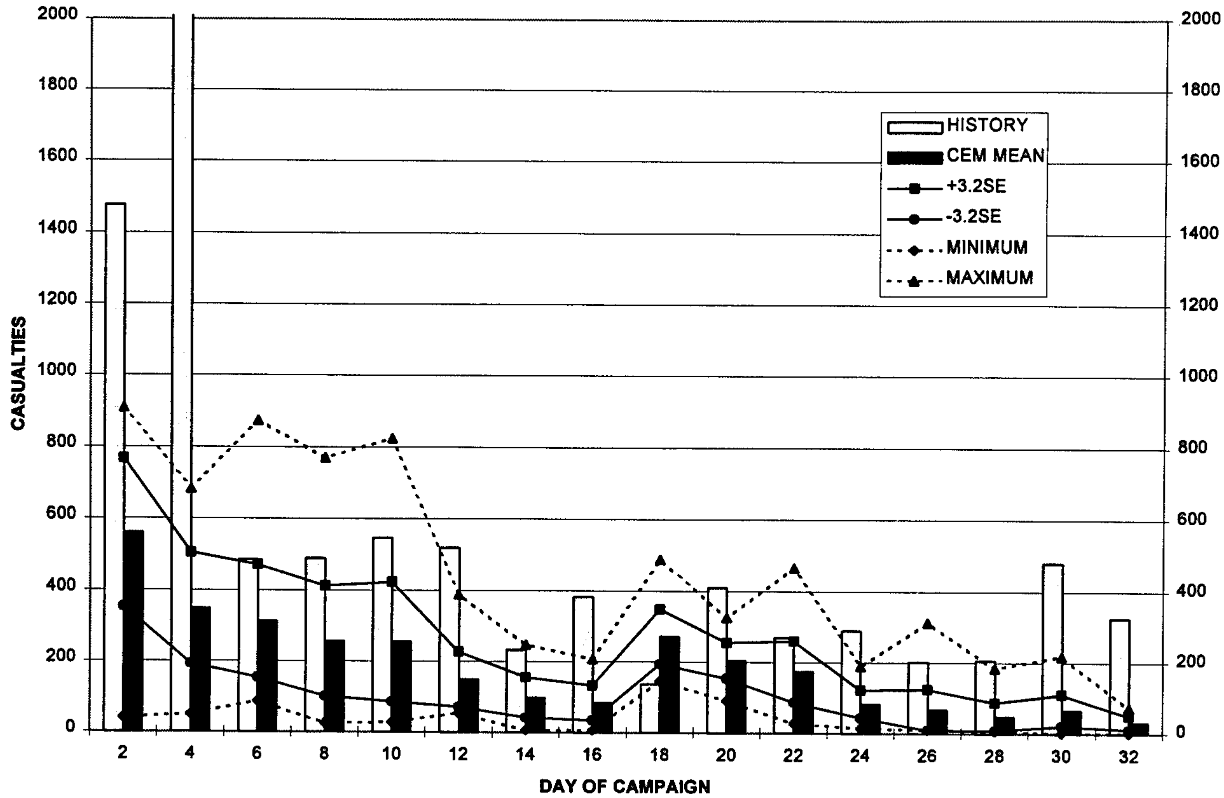


Figure H-5. US/UK Daily CMIA Closeup (base case)

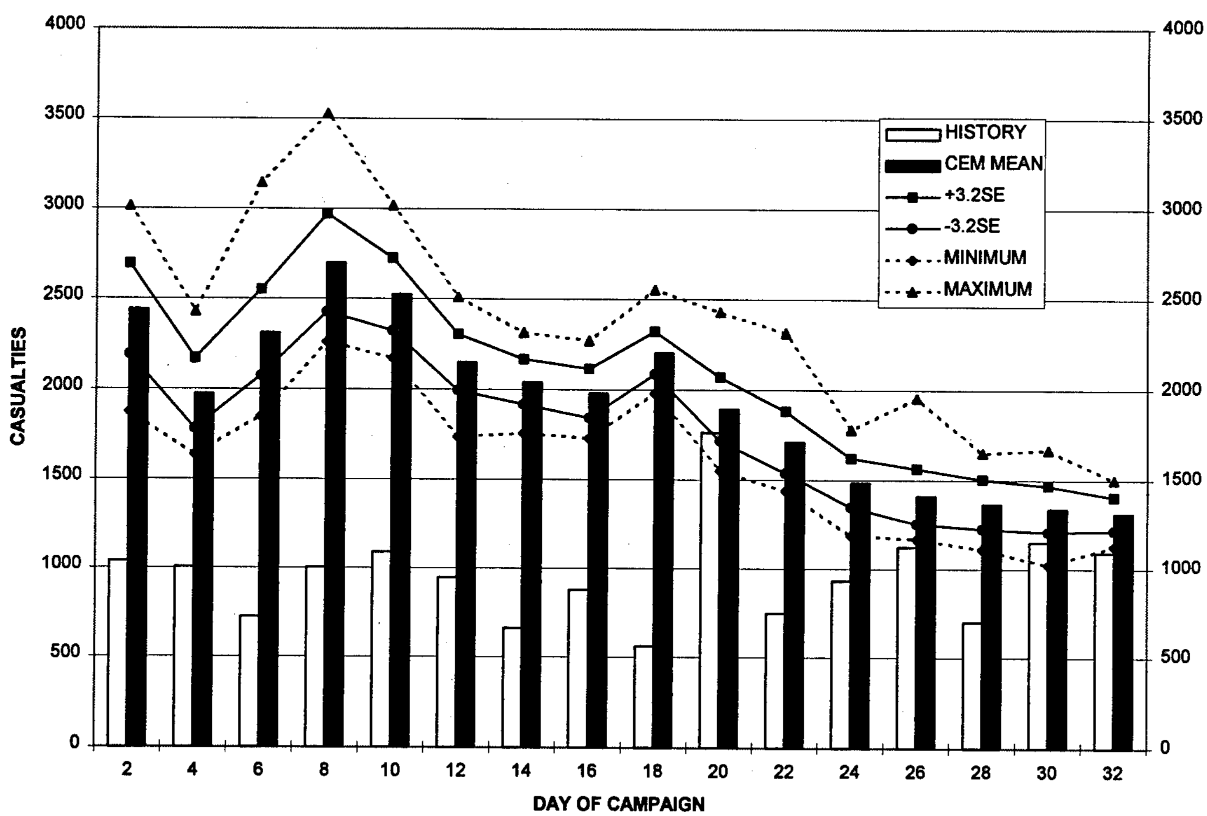


Figure H-6. US/UK Daily WIA (base case)

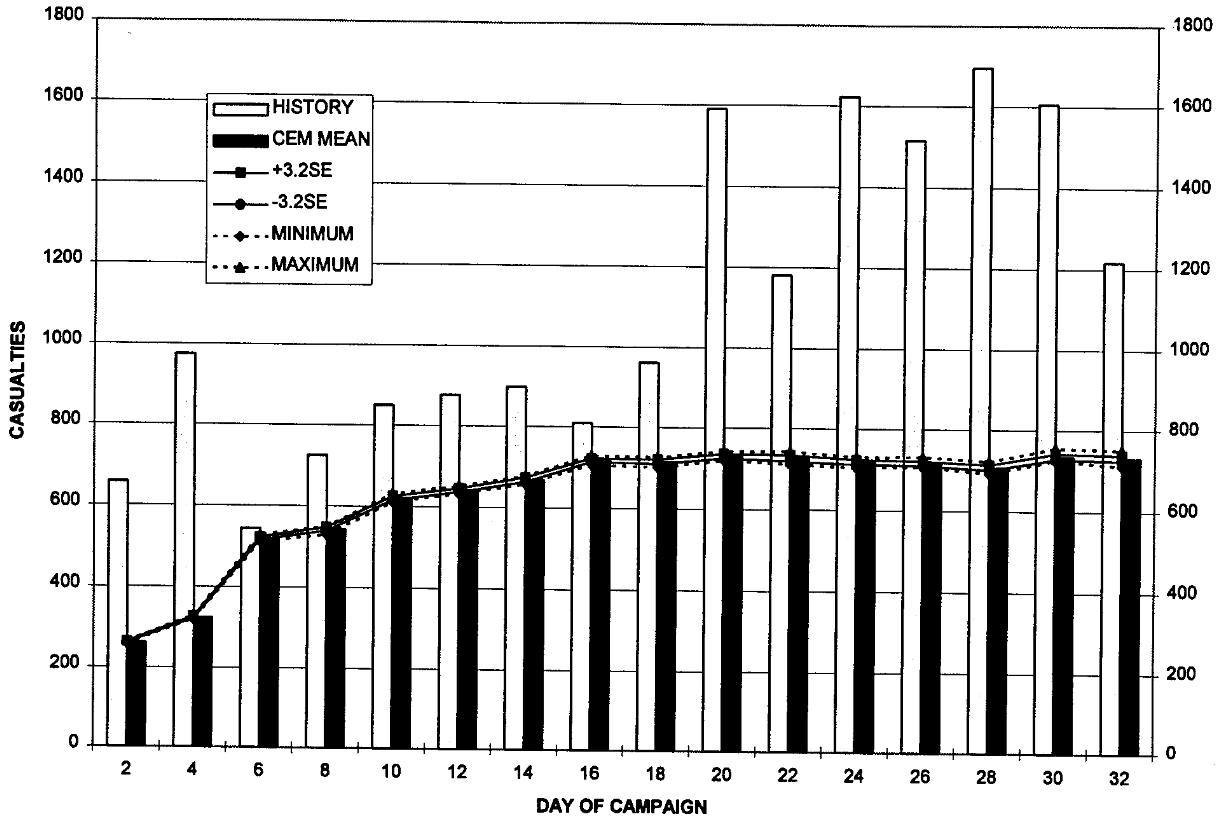


Figure H-7. US/UK Daily DNBI (base case)

H-6. EXCURSION CASE DAILY CASUALTIES. Figures H-8 through H-14 compare historical daily casualties with STOCEM excursion case daily casualties for each casualty type and for selected combinations of casualty types. (Historical casualties in these figures are identical with historical casualties in the base case.) The figures include only casualties in the line units available for commitment to the campaign in the ARCAS scenario, as reflected in Table 2-2. Results are plotted for every second day of the campaign.

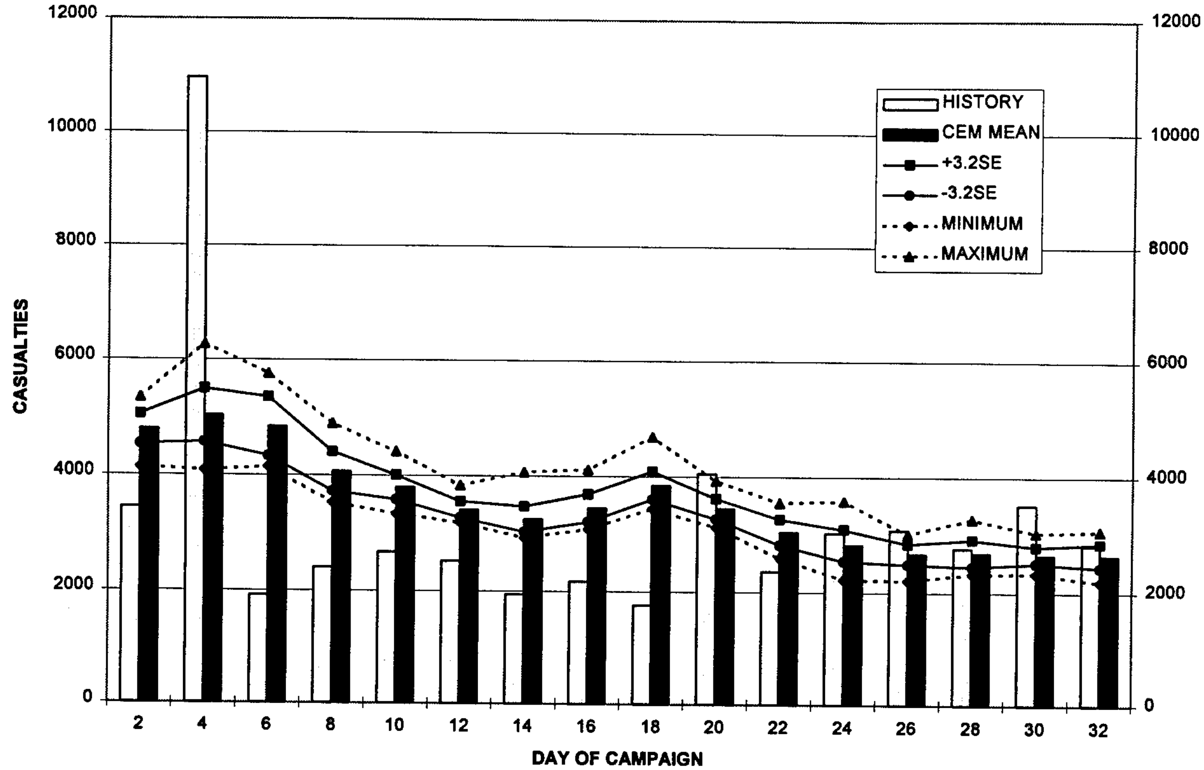


Figure H-8. US/UK Daily Casualties (excursion case): KCMIA + WIA and DNBI

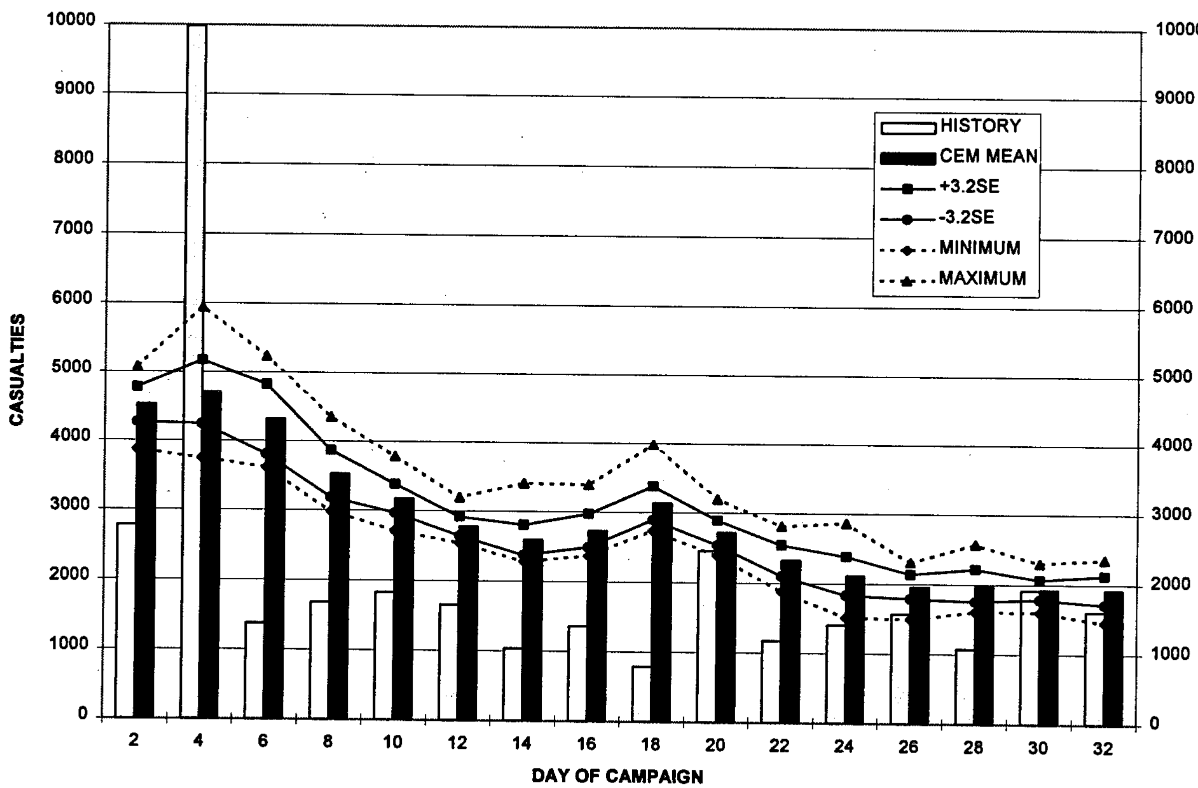


Figure H-9. US/UK Daily Combat Casualties (excursion case): KCMIA + WIA

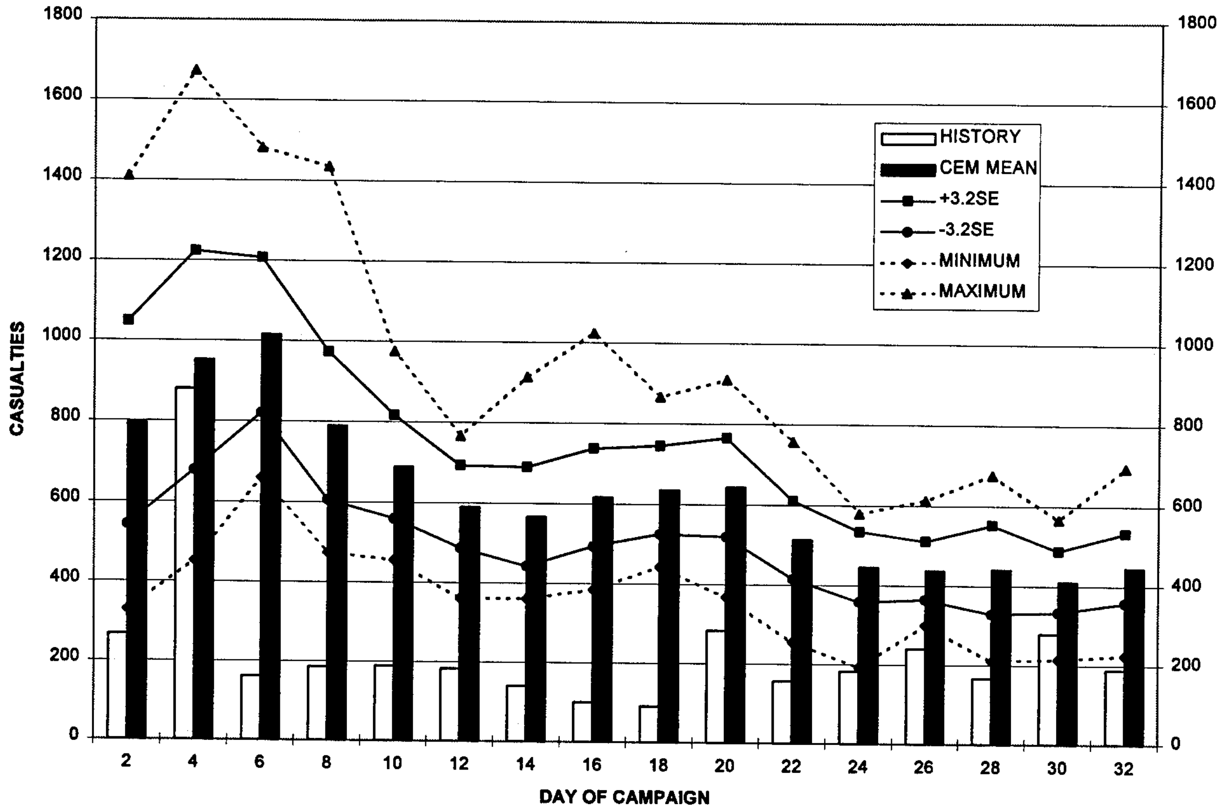


Figure H-10. US/UK Daily KIA (excursion case)

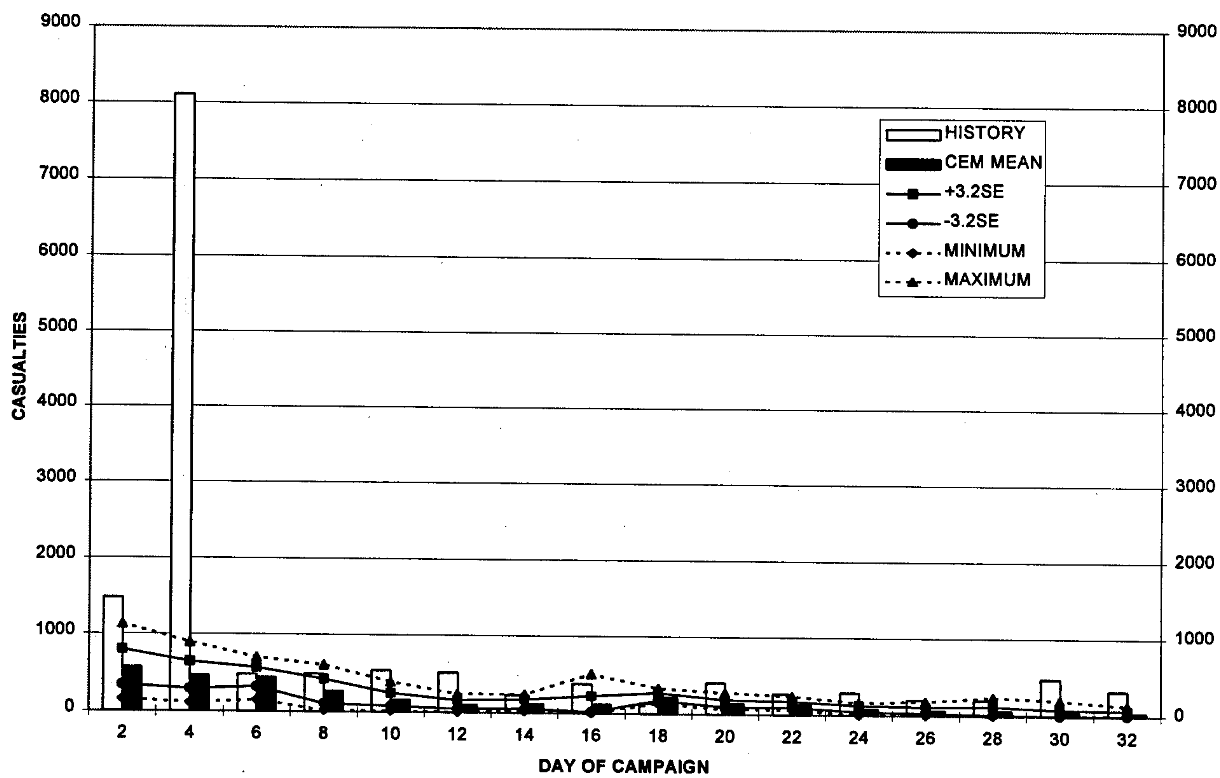


Figure H-11. US/UK Daily CMIA (excursion case)

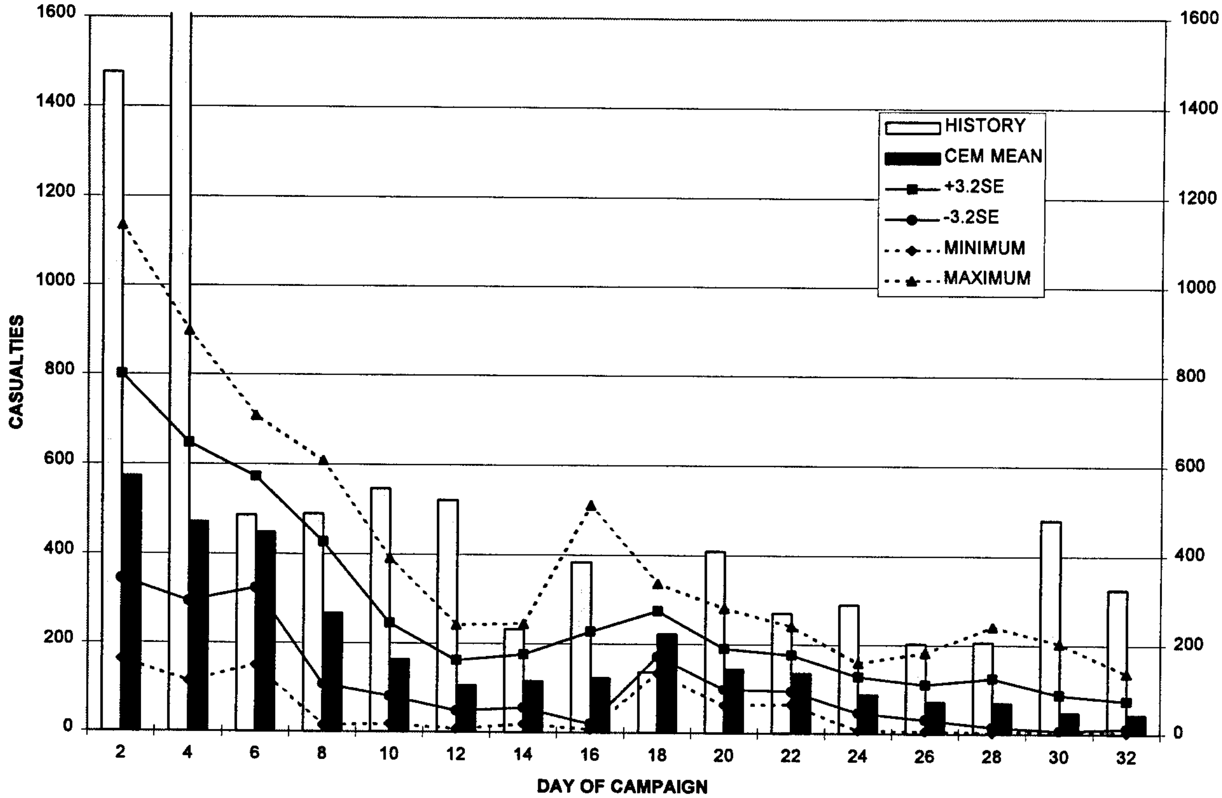


Figure H-12. US/UK Daily CMIA Closeup (excursion case)

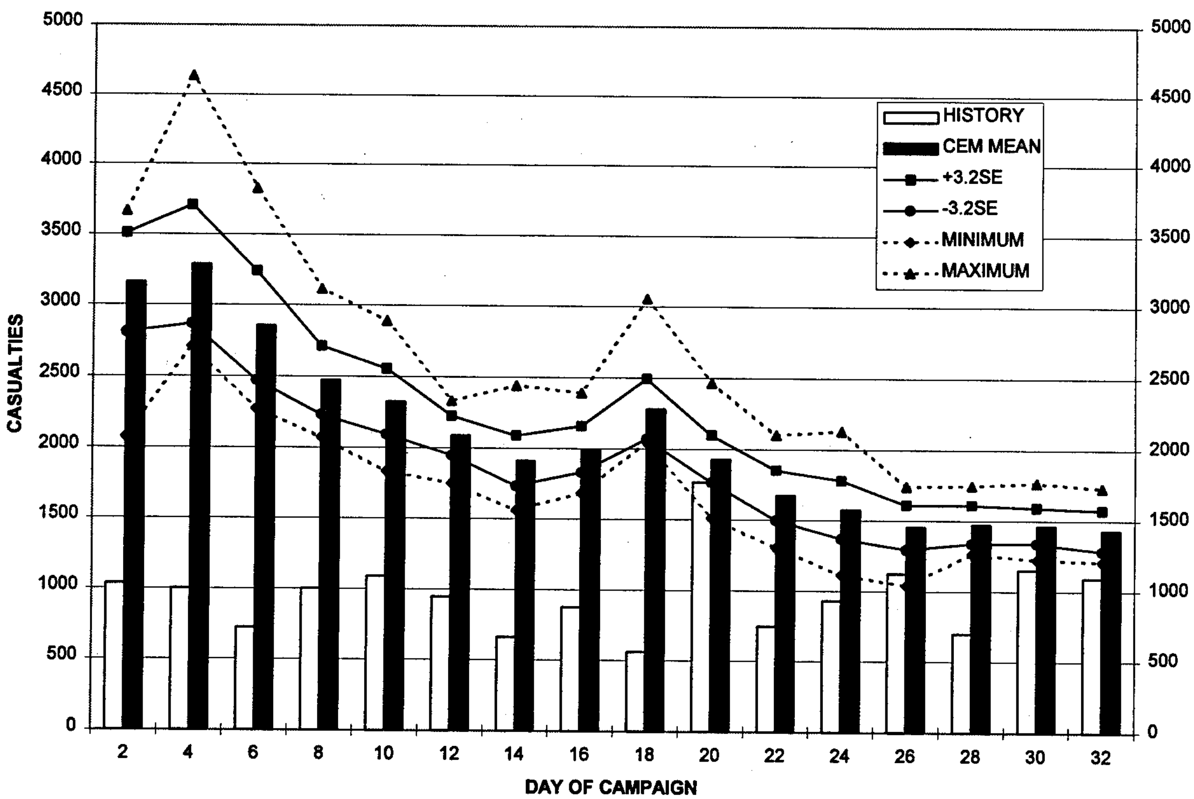


Figure H-13. US/UK Daily WIA (excursion case)

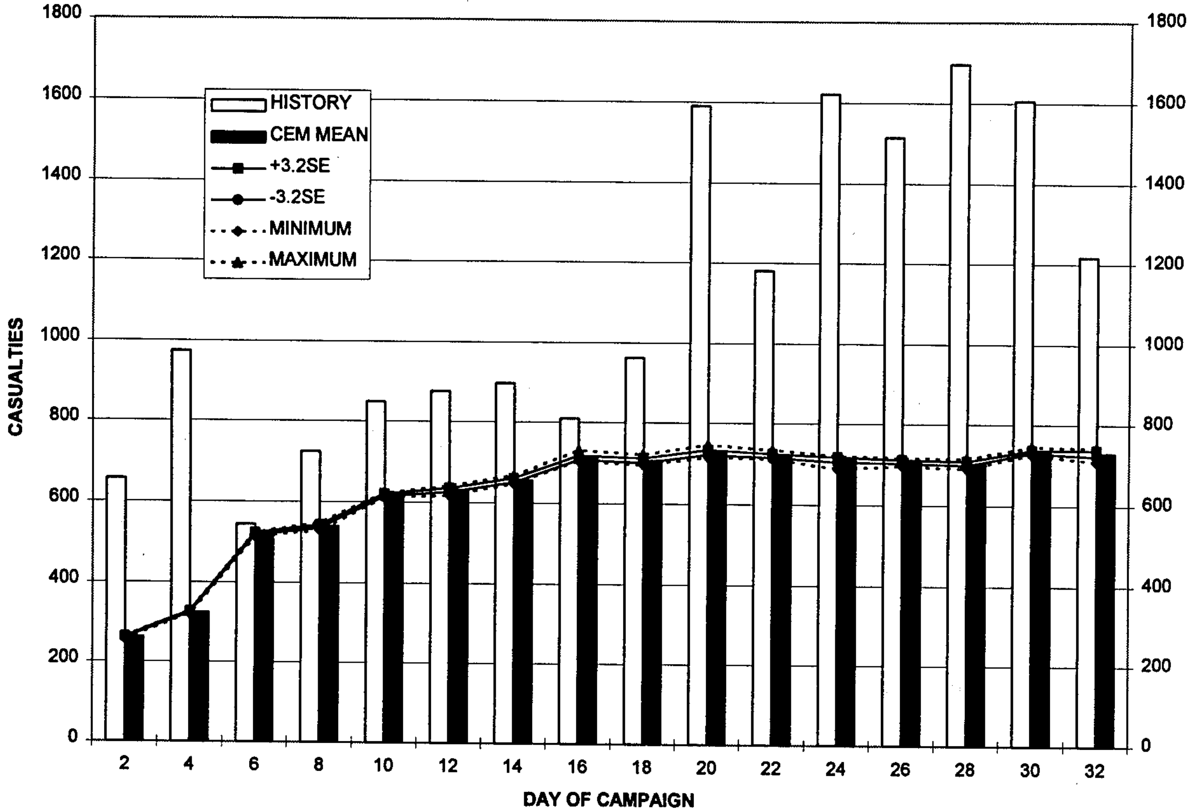
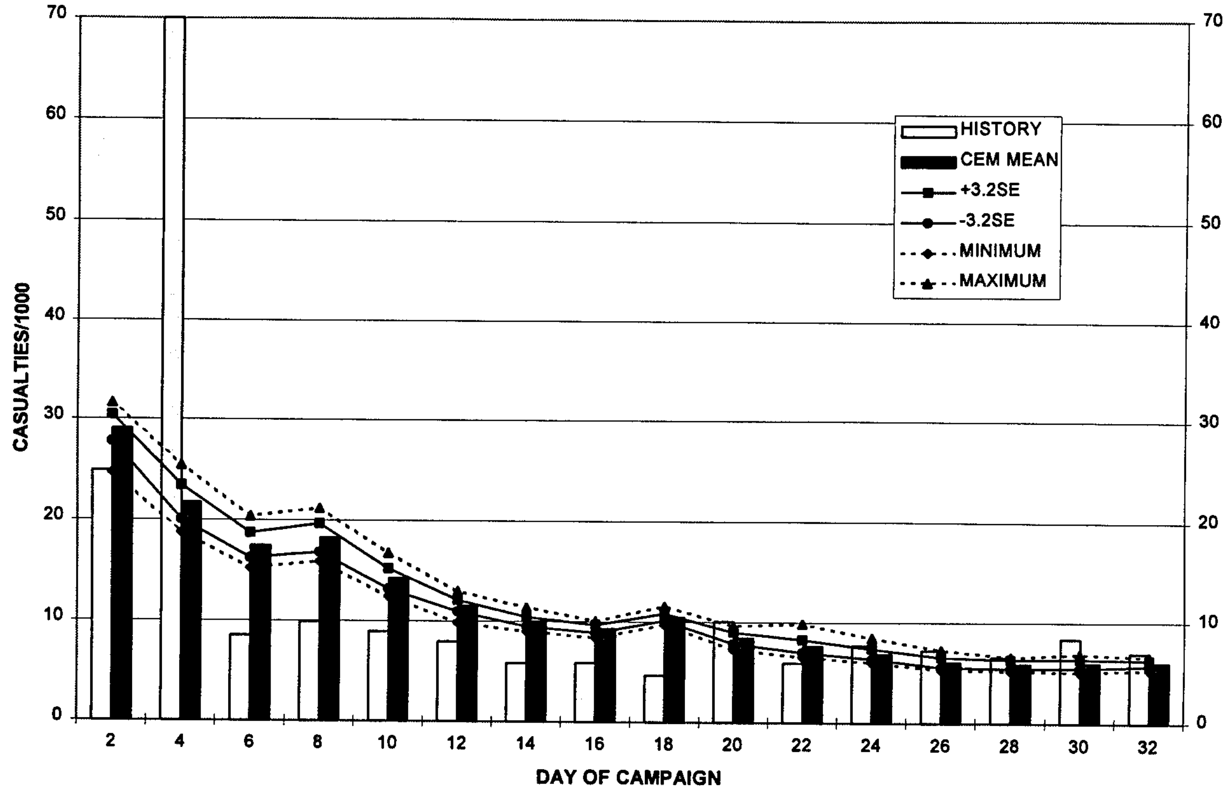
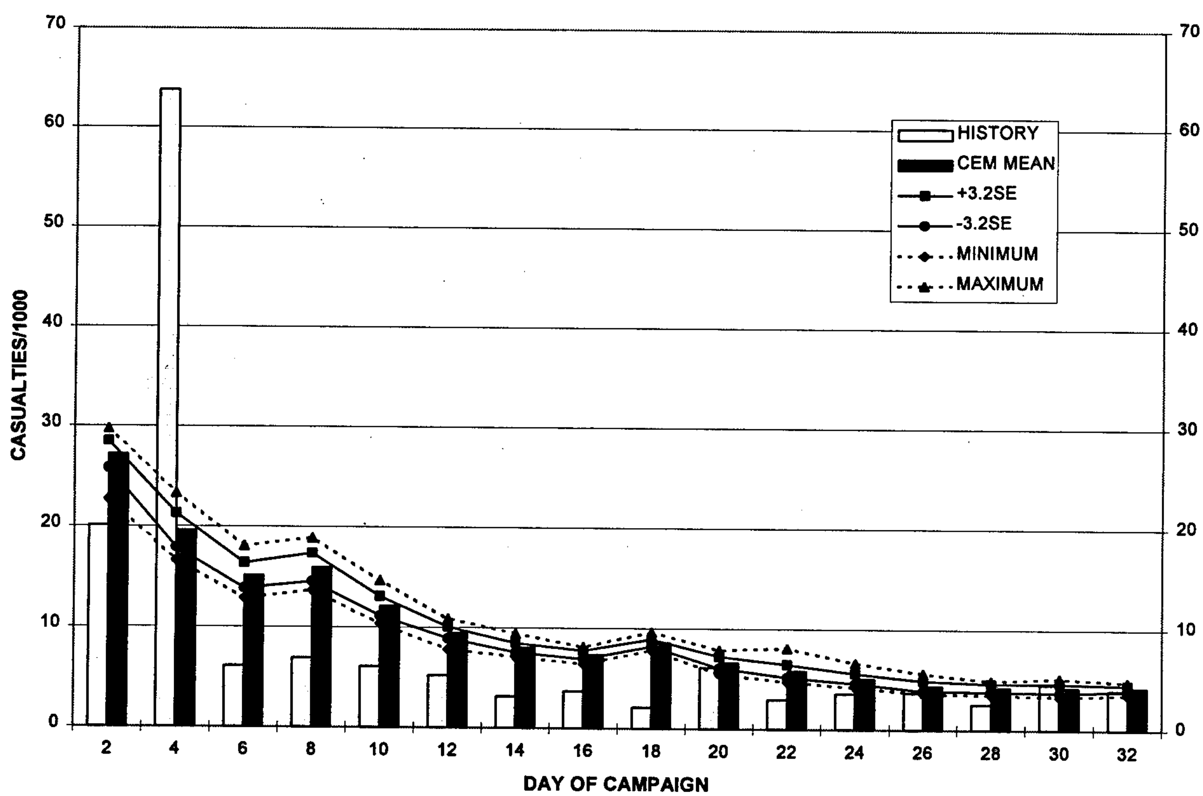


Figure H-14. US/UK Daily DNBI (excursion case)

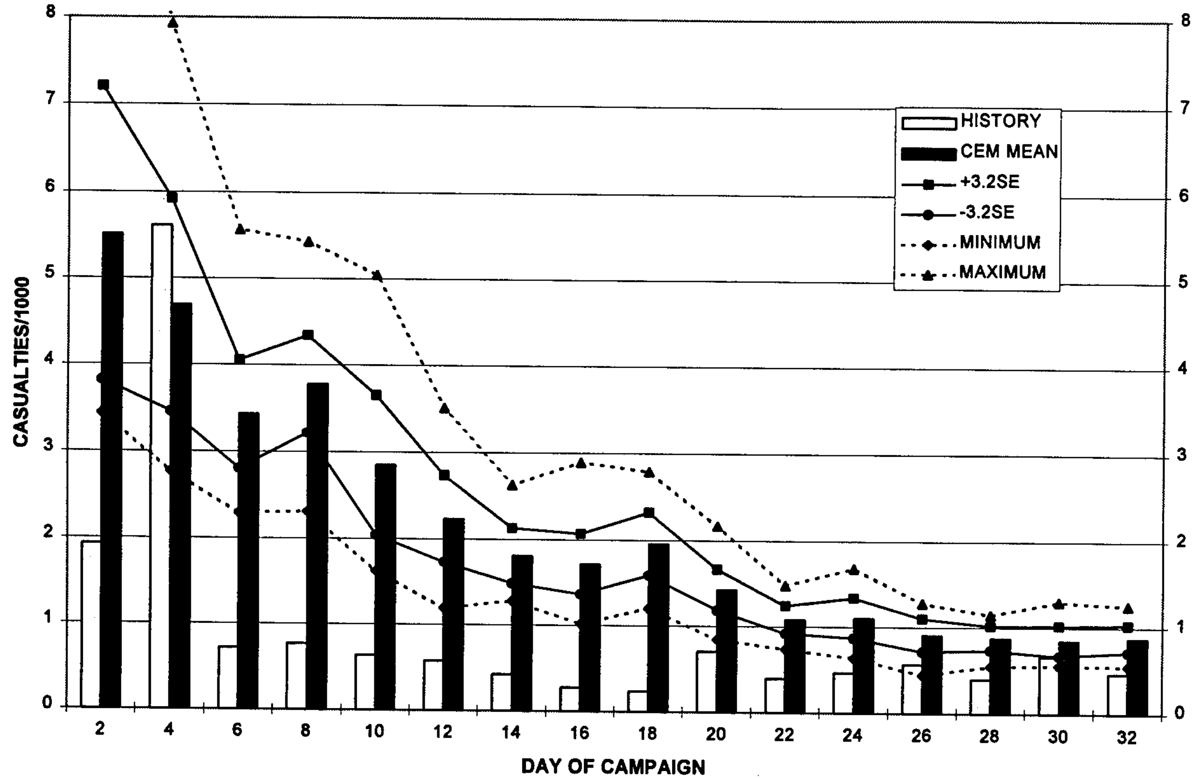
H-7. STOCEM BASE CASE DAILY CASUALTY RATES. Figures H-15 through H-21 compare historical daily casualty rates with STOCEM base case daily casualty rates for each casualty type and for selected combinations of casualty types. Casualty rates are expressed as casualties per thousand onhand personnel in the line units available for commitment to the campaign. The casualty types included in the results portrayed are identified in the title of each figure. The figures include only casualties in the line units available for commitment to the campaign in the ARCAS scenario, as reflected in Table 2-2. Results are plotted for every second day of the campaign (days 2, 4, 6, 8 . . .).



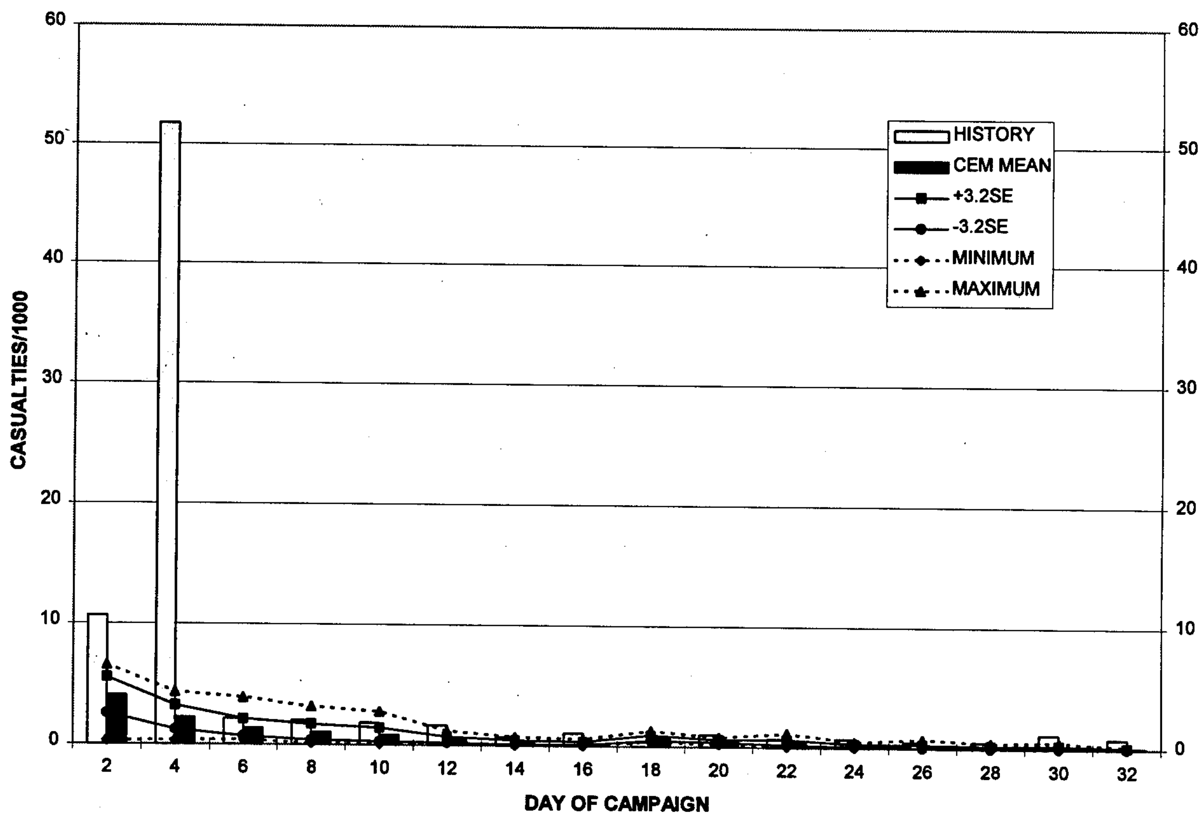
H-15. US/UK Daily Casualty Rate (base case): KCMIA + WIA and DNBI



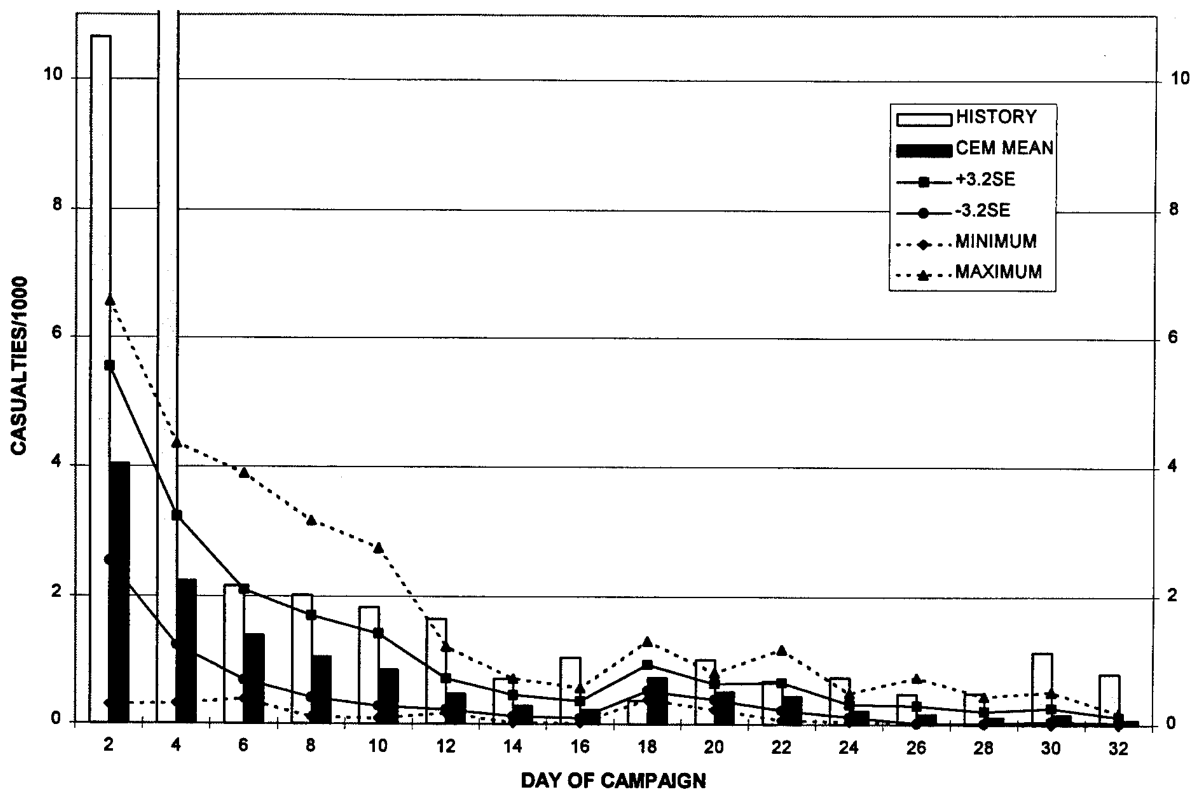
H-16. US/UK Daily Combat Casualty Rate (base case): KCMIA + WIA



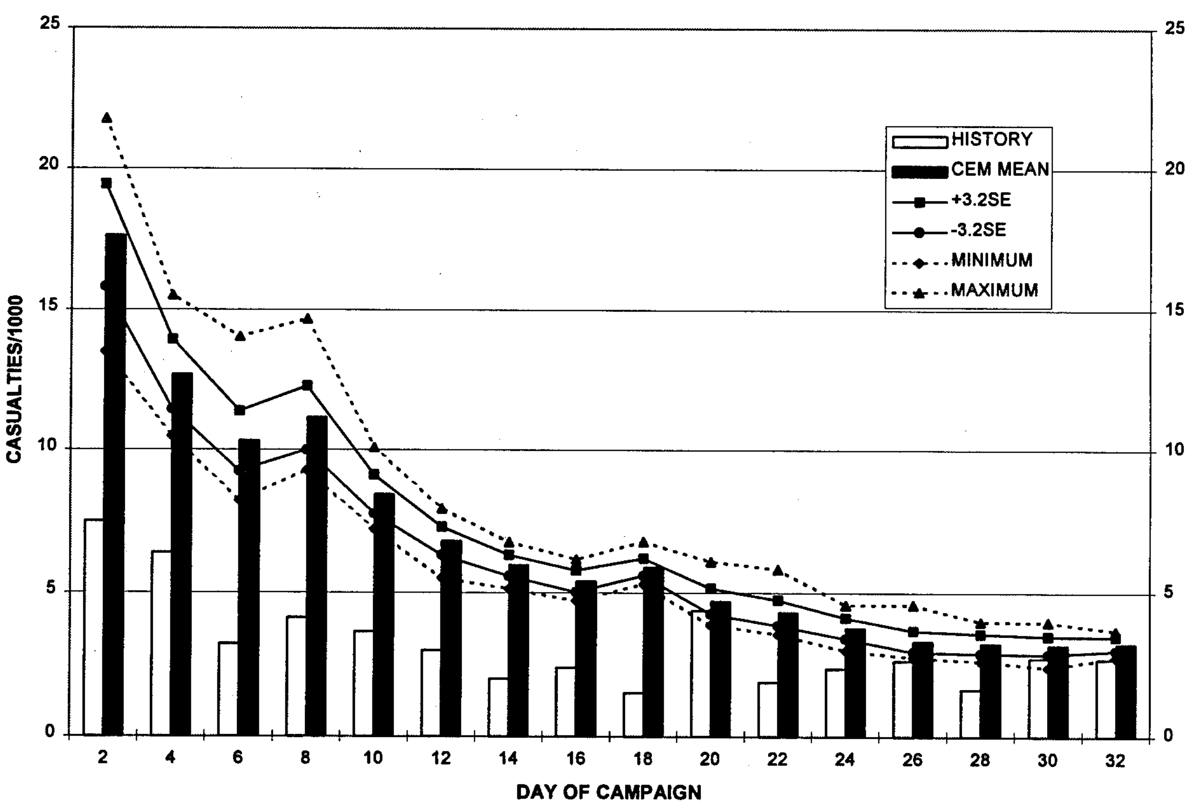
H-17. US/UK Daily KIA Casualty Rate (base case)



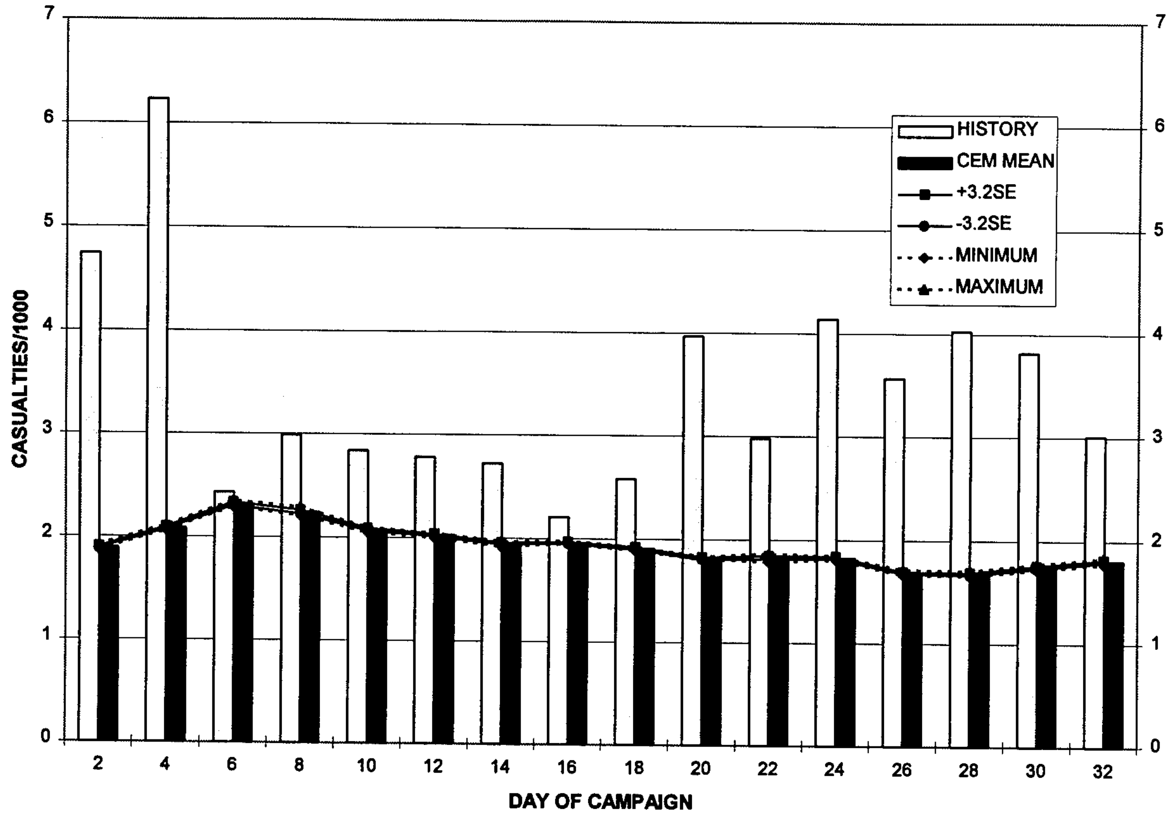
H-18. US/UK Daily CMIA Casualty Rate (base case)



H-19. US/UK Daily CMIA Casualty Rate Closeup (base case)

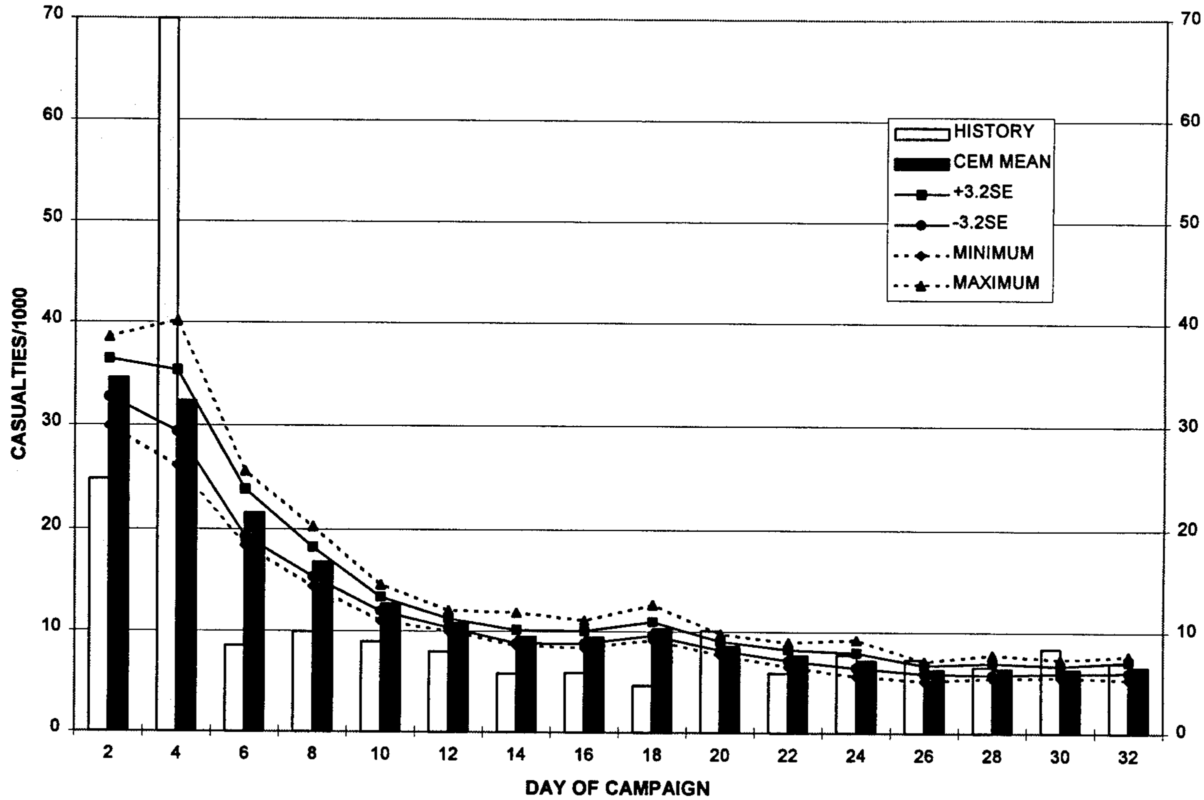


H-20. US/UK Daily WIA Casualty Rate (base case)

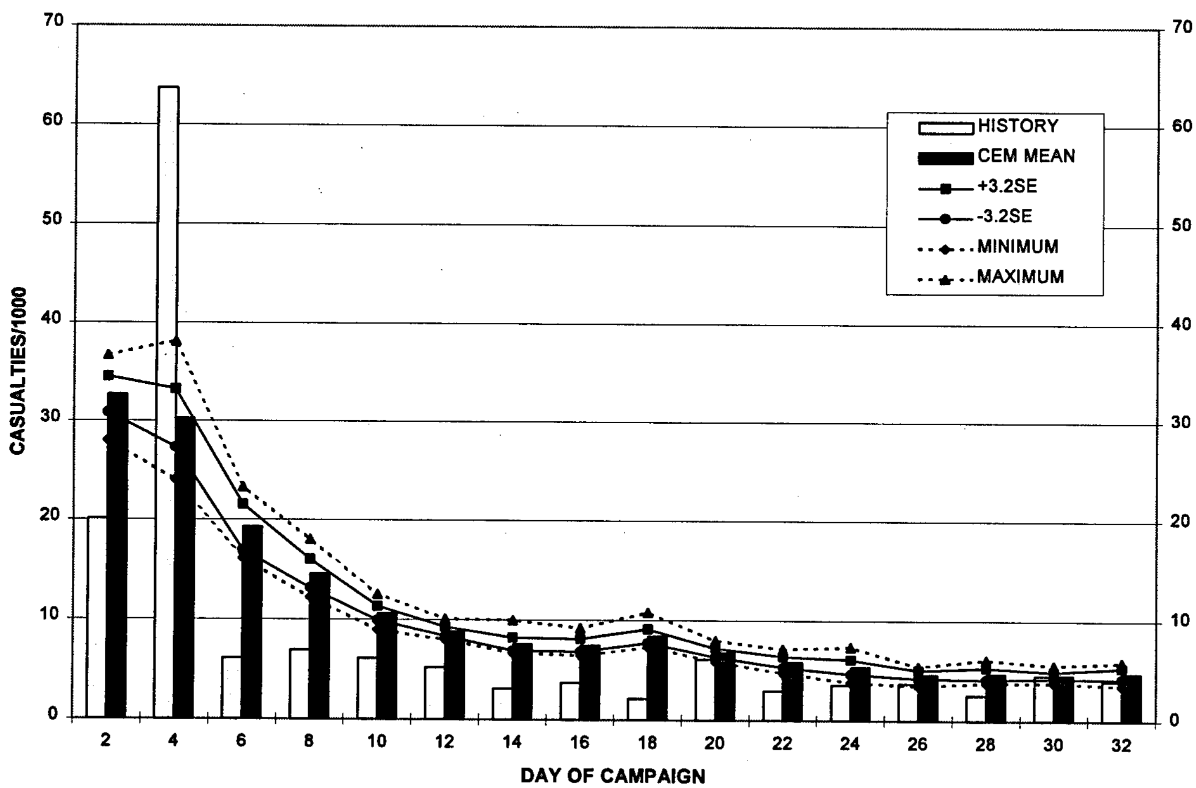


H-21. US/UK Daily DNBI Casualty Rate (base case)

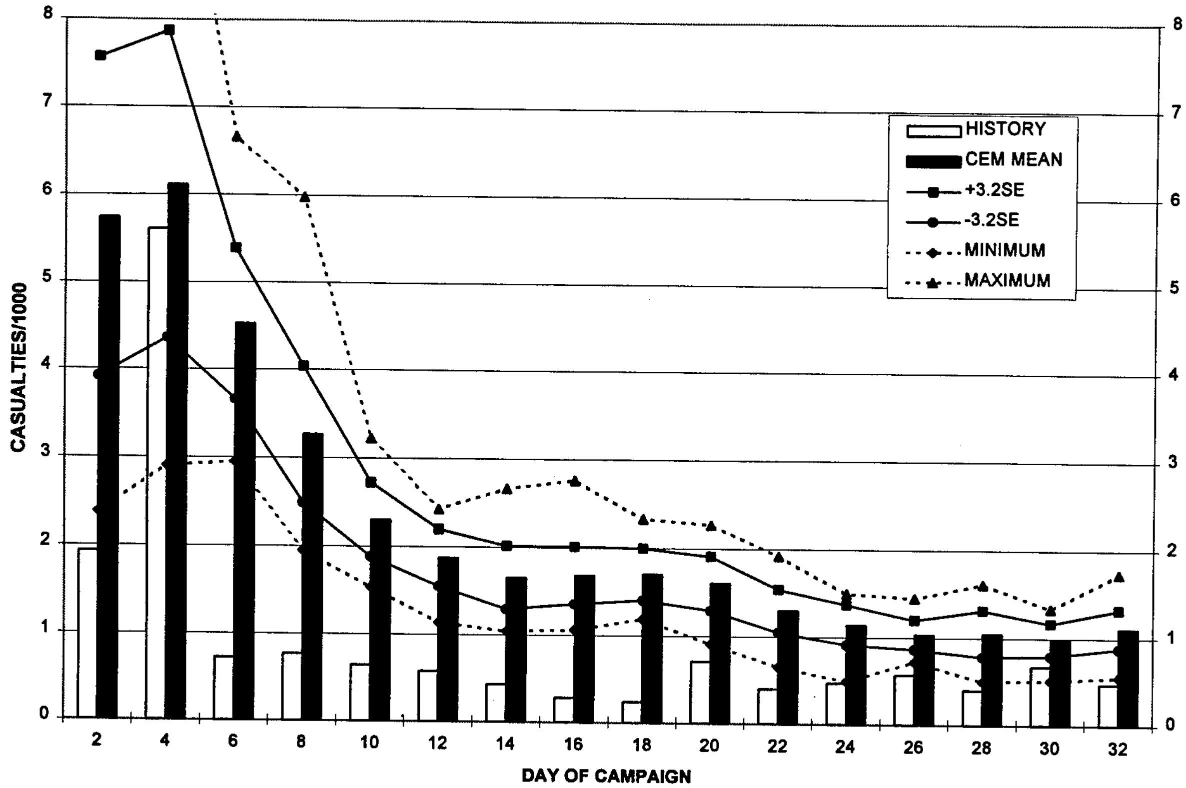
H-8. STOCEM EXCURSION CASE DAILY CASUALTY RATES. Figures H-22 through H-28 compare historical daily casualty rates with STOCEM excursion case daily casualty rates for each casualty type and for selected combinations of casualty types. Casualty rates are expressed as casualties per thousand onhand personnel in the line units available for commitment to the campaign. The casualty types included in the results portrayed are identified in the title of each figure. (Historical casualties in these figures are identical with historical casualties in the base case.) The figures include only casualties in the line units available for commitment to the campaign in the ARCAS scenario, as reflected in Table 2-2. Results are plotted for every second day of the campaign.



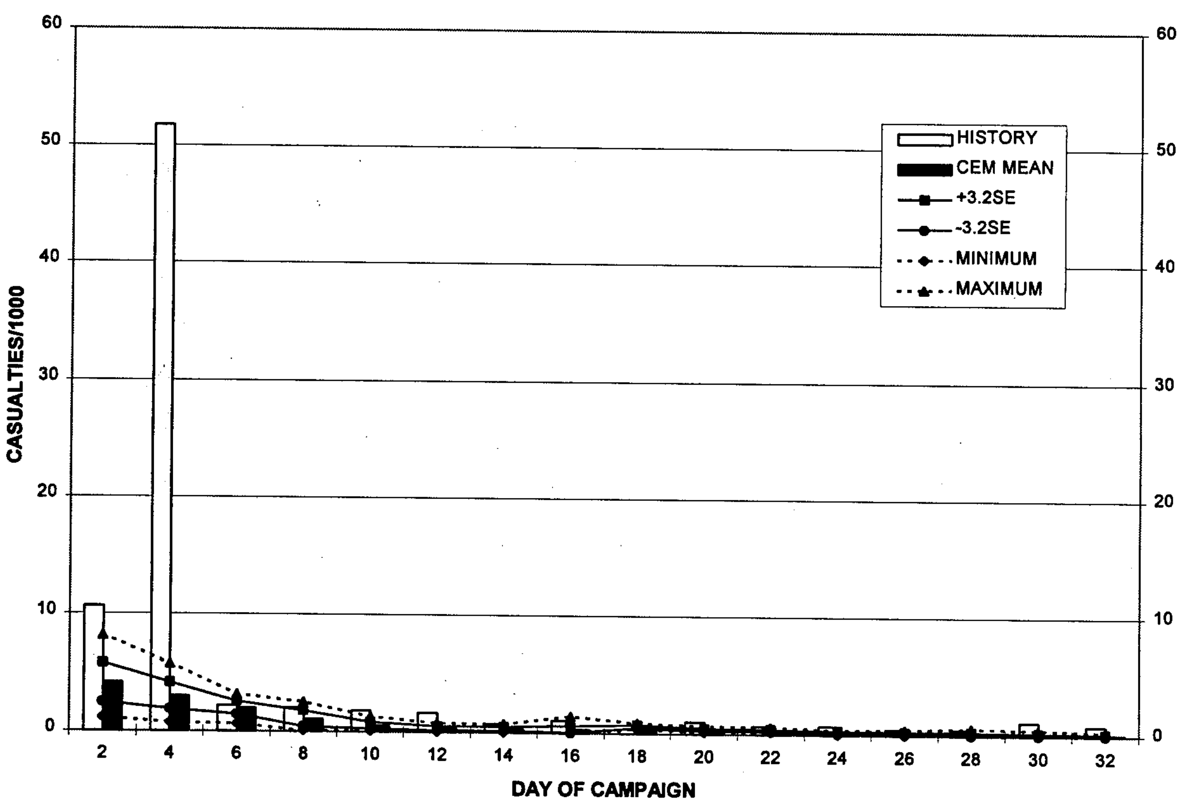
H-22. US/UK Daily Casualty Rate (excursion case): KCMIA + WIA and DNBI



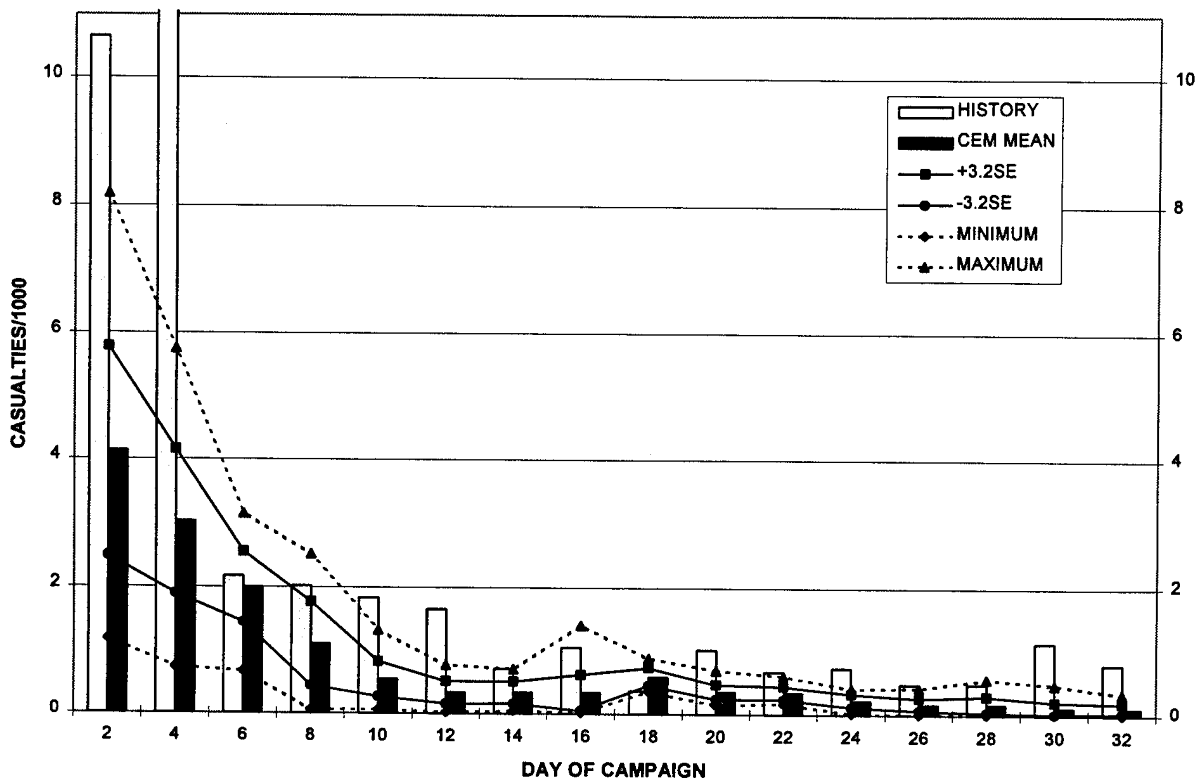
H-23. US/UK Daily Combat Casualty Rate (excursion case): KCMIA + WIA



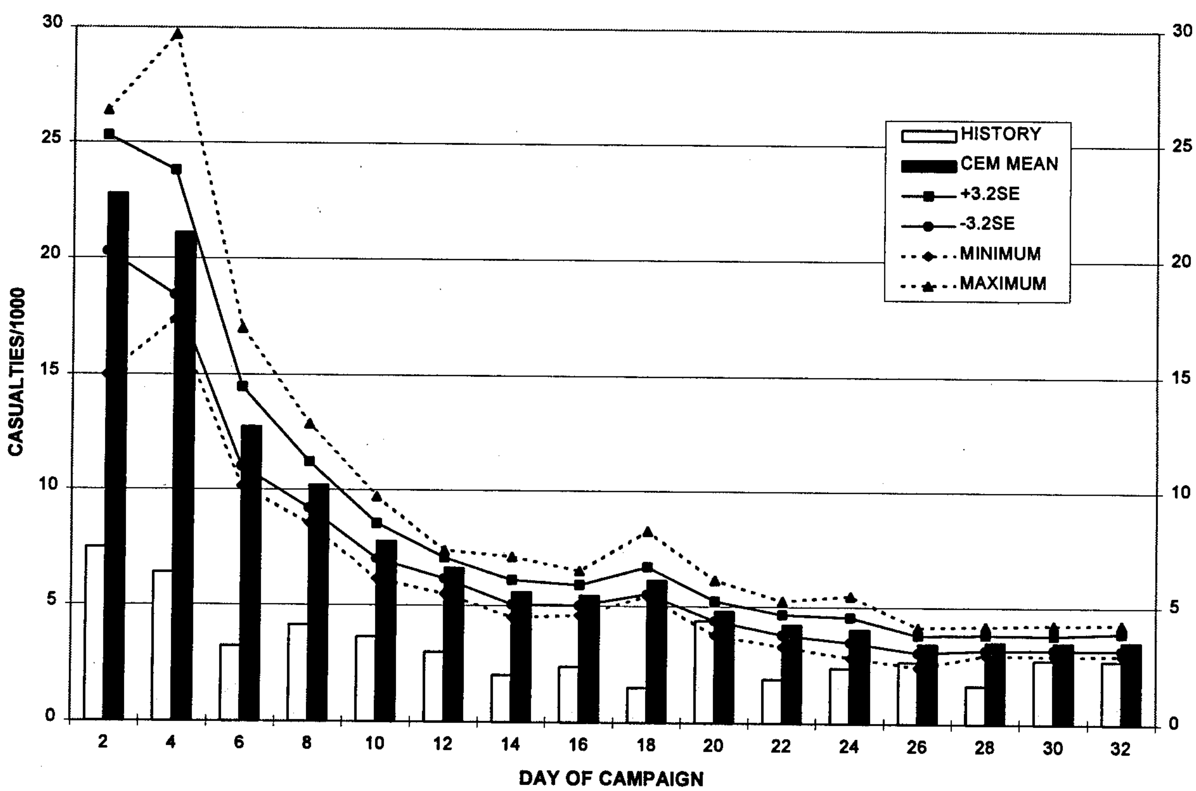
H-24. US/UK Daily KIA Casualty Rate (excursion case)



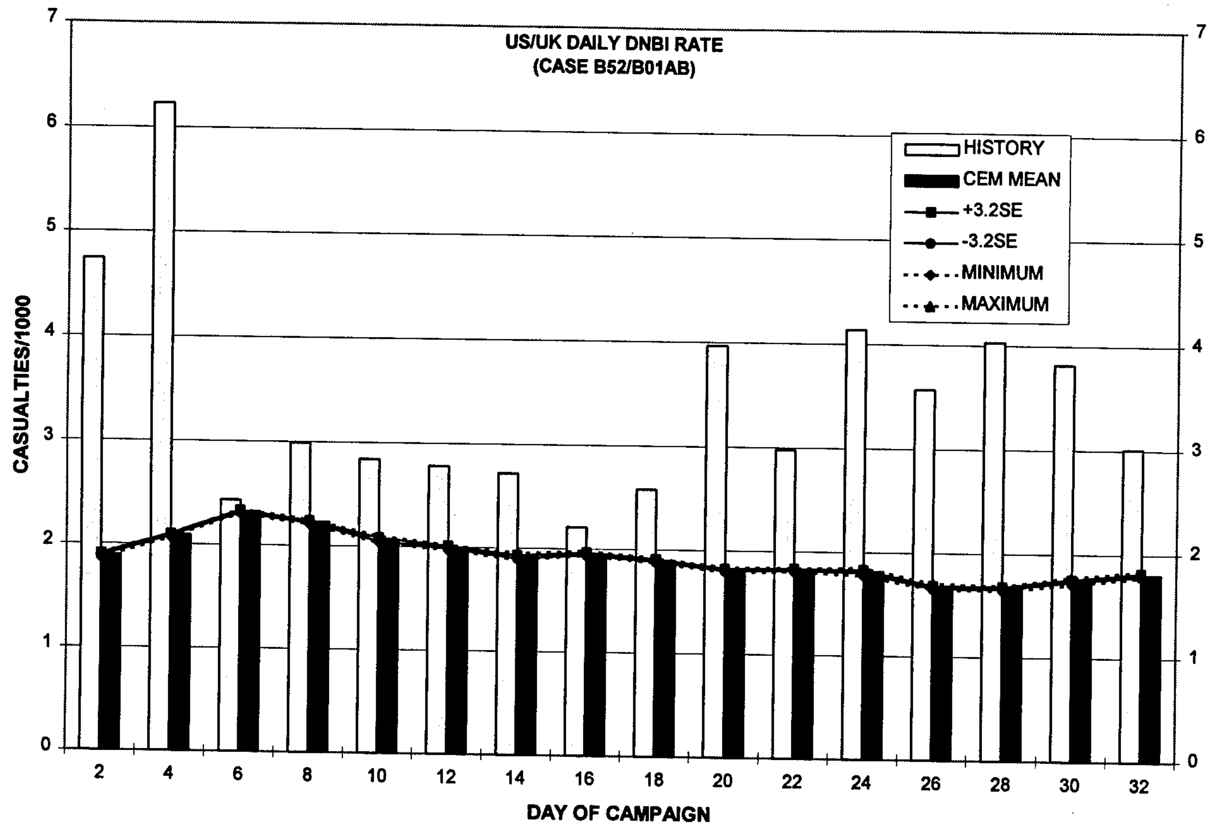
H-25. US/UK Daily CMIA Casualty Rate (excursion case)



H-26. US/UK Daily CMIA Casualty Rate Closeup (excursion case)



H-27. US/UK Daily WIA Casualty Rate (excursion case)



H-28. US/UK Daily DNBI Casualty Rate (excursion case)

H-9. STOCEM BASE CASE DAILY CASUALTY PROPORTIONS IN EACH CASUALTY TYPE. Figure H-29 shows the proportion of total historical daily casualties in each casualty type. Figure H-30 shows the average proportion of total STOCEM base case daily casualties in each casualty type. Figures H-31 through H-34 compare the proportions of historical daily casualties in each casualty type with the corresponding proportions of STOCEM base case daily casualties. STOCEM uncertainty limits are also charted. All proportions are relative to the total daily casualties shown in Figure H-1. Results are plotted for every second day of the campaign.

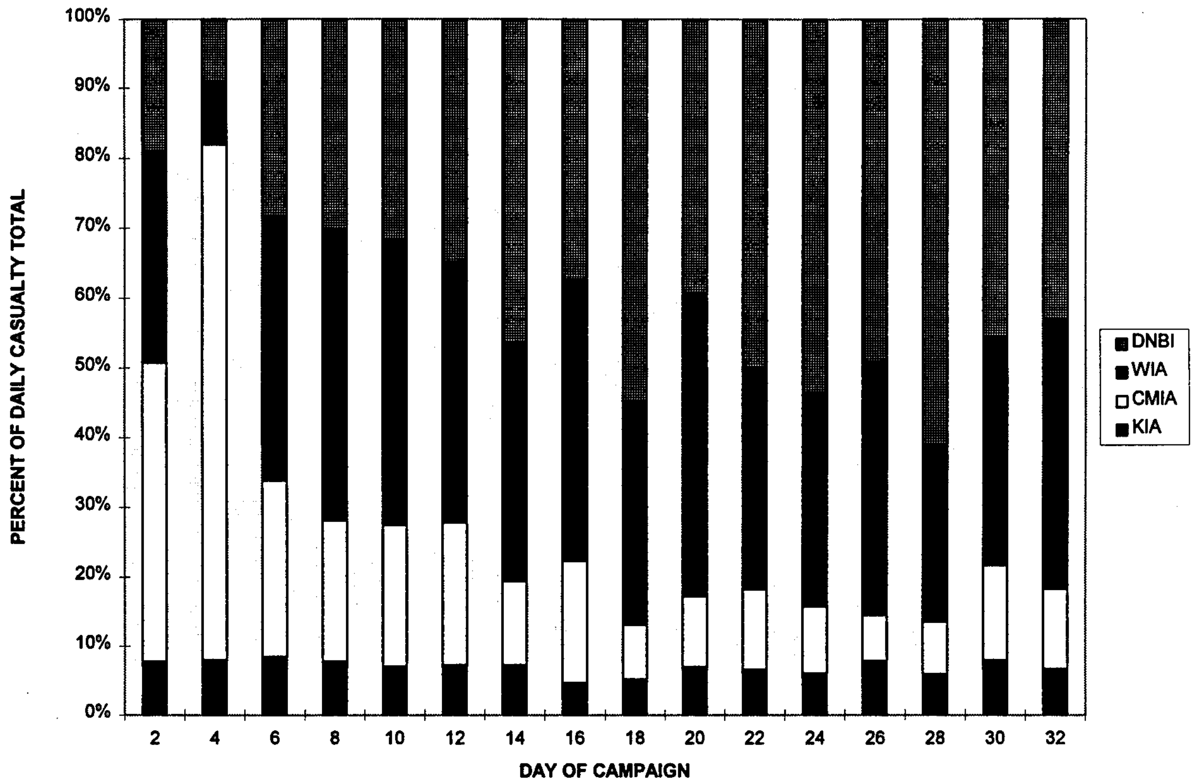


Figure H-29. Proportion of Total Historical Daily Casualties in Each Casualty Type

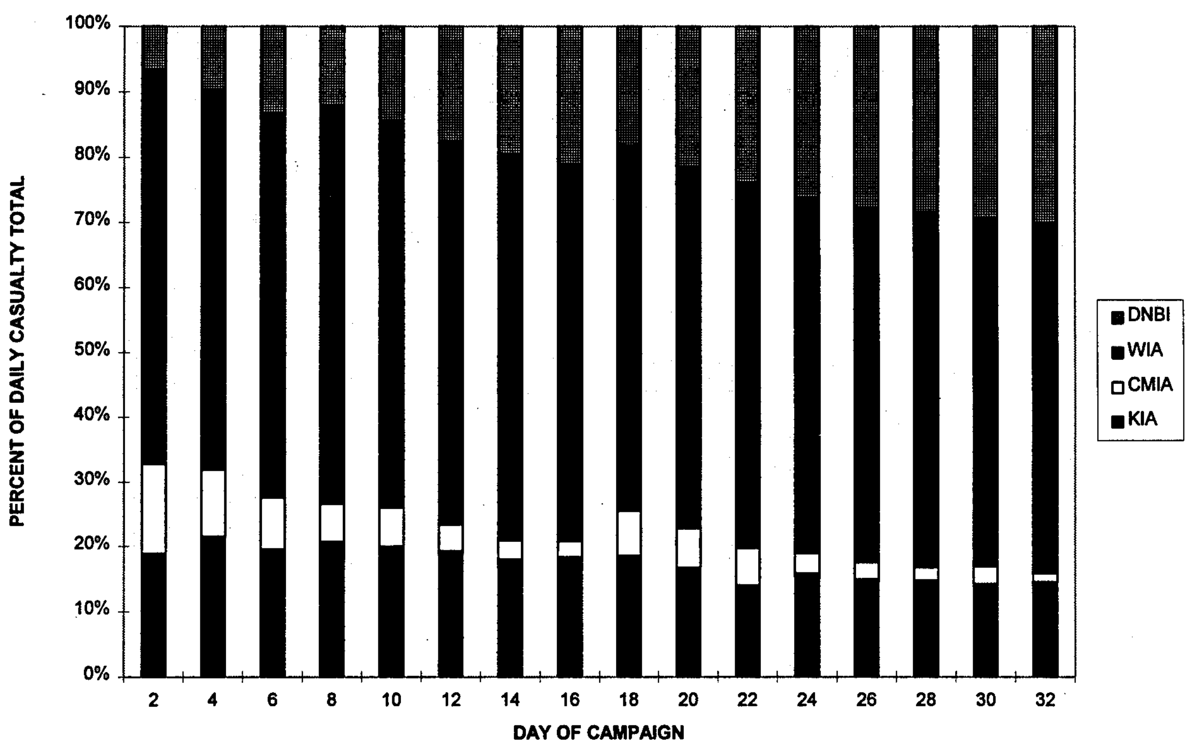


Figure H-30. Proportion of Total STOCEM Base Case Daily Casualties in Each Casualty Type

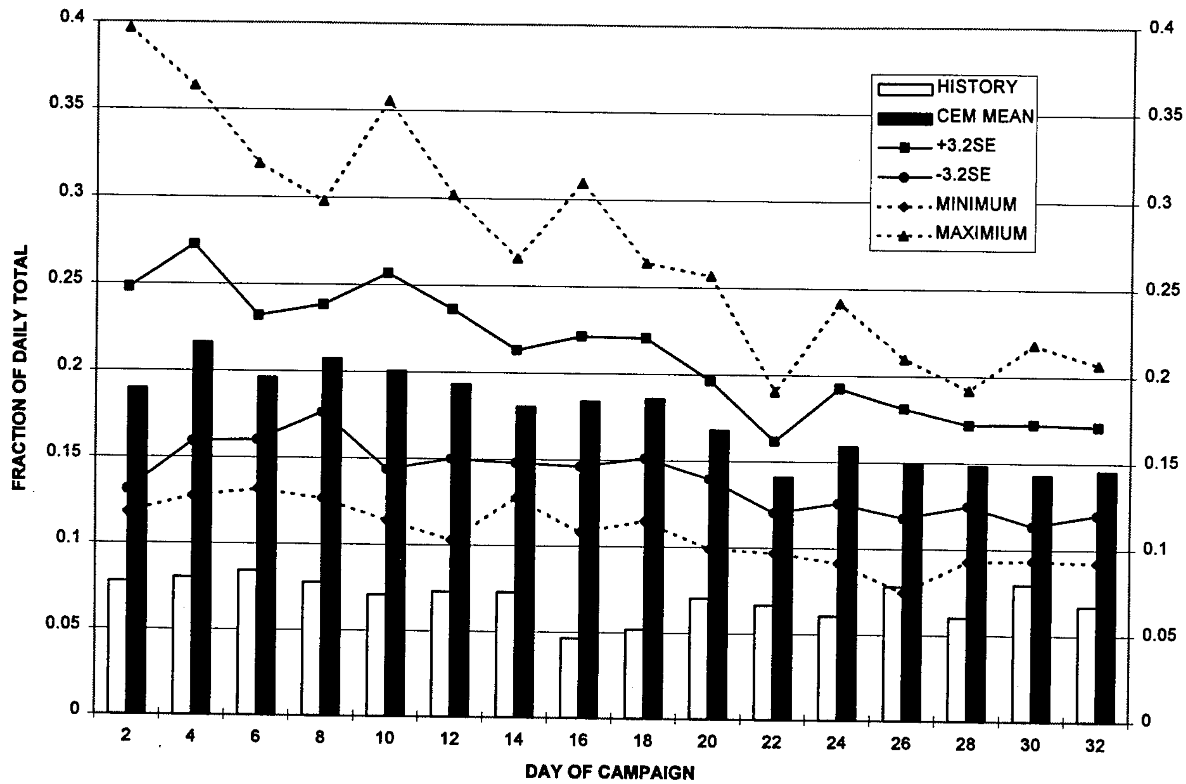


Figure H-31. Fraction KIA in Total Daily Casualties (STOCEM base case vs history)

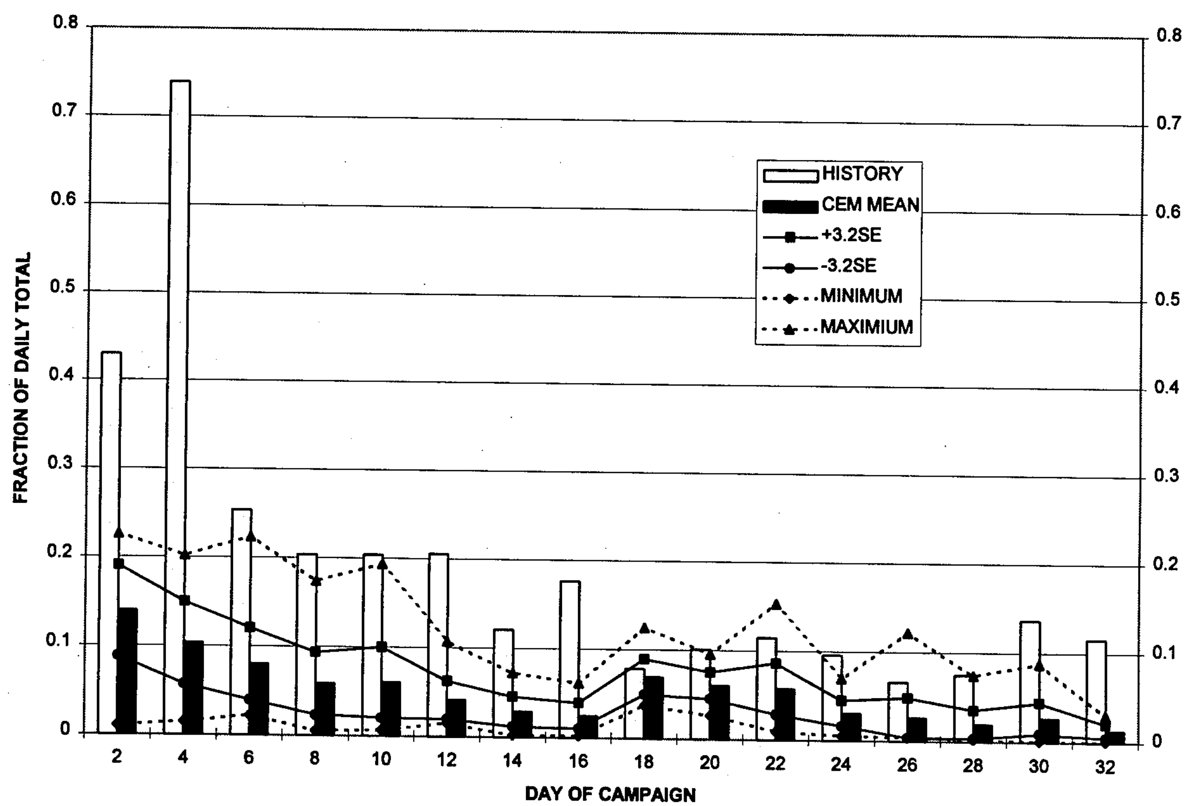


Figure H-32. Fraction CMIA in Total Daily Casualties (STOCEM base case vs history)

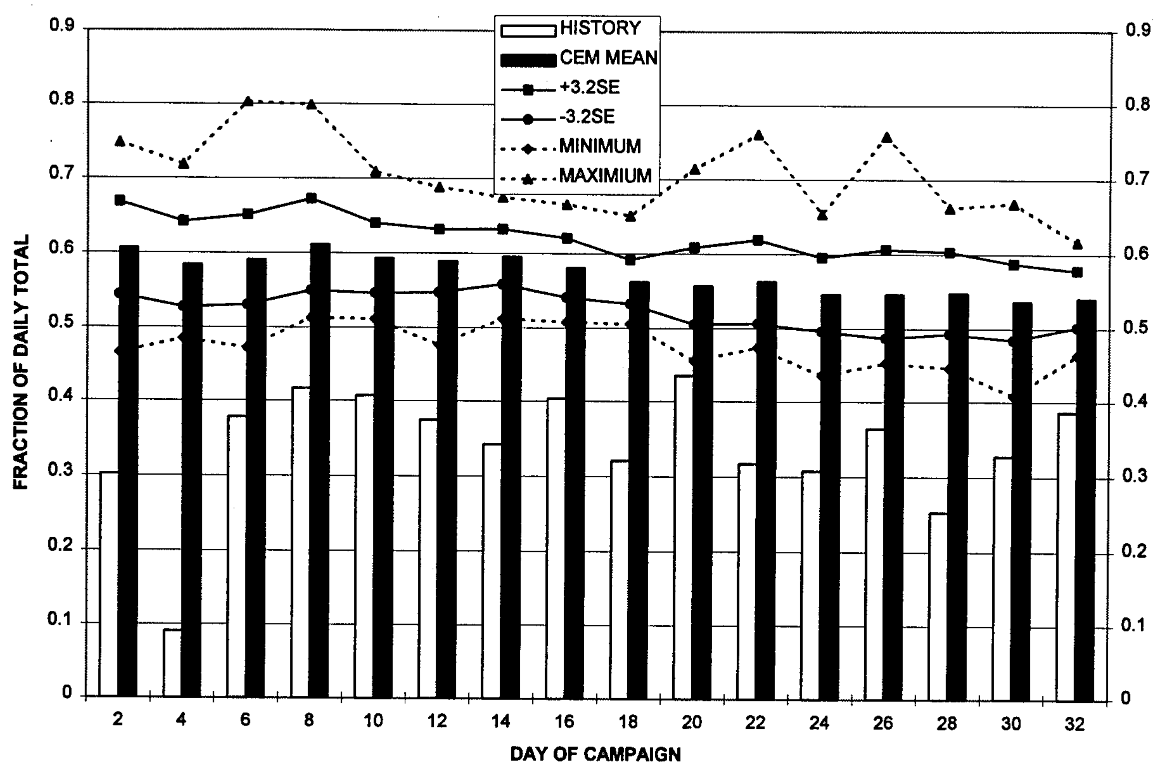


Figure H-33. Fraction WIA in Total Daily Casualties (STOCEM base case vs history)

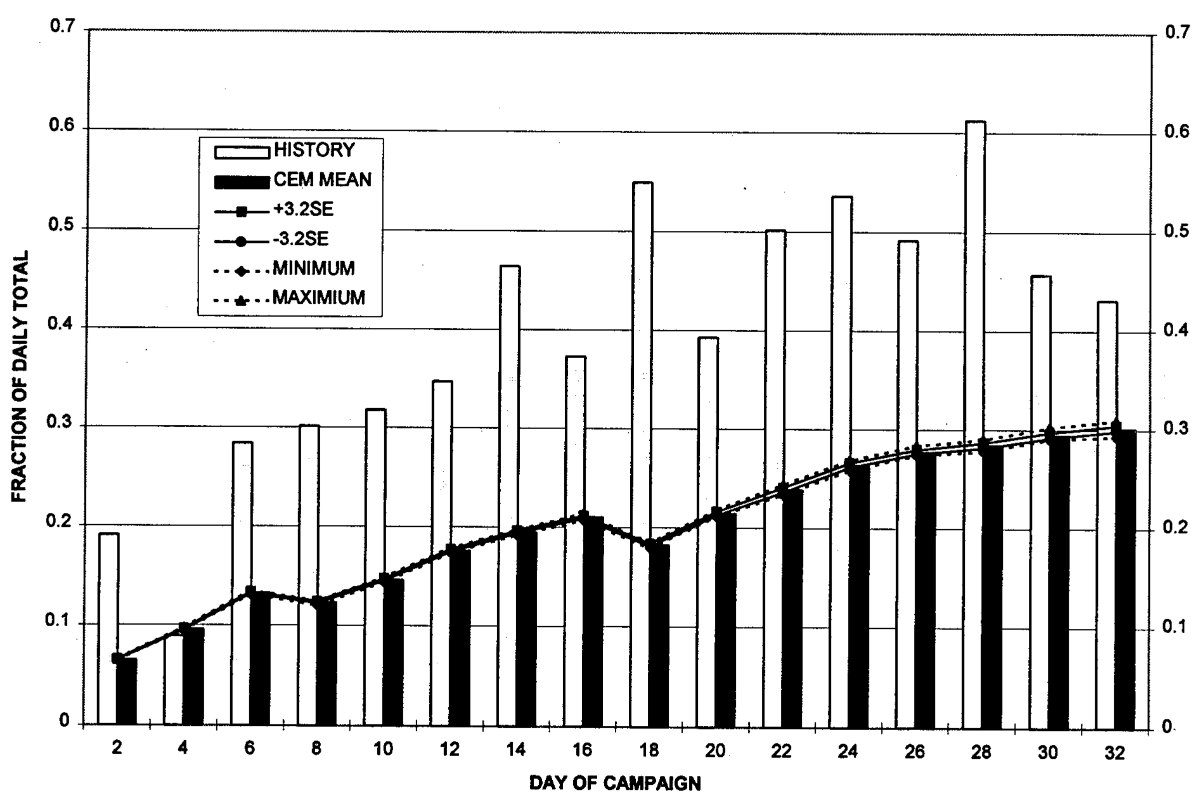


Figure H-34. Fraction DNBI in Total Daily Casualties (STOCEM base case vs history)

H-10. STOCEM EXCURSION CASE DAILY CASUALTY PROPORTIONS IN EACH CASUALTY TYPE. Figure H-35 shows the average proportion of total STOCEM excursion case daily casualties in each casualty type. Figures H-36 through H-39 compare the proportions of historical daily casualties in each casualty type with the corresponding proportions of STOCEM excursion case daily casualties. STOCEM uncertainty limits are also charted. All proportions are relative to the total daily casualties shown in Figure H-8. Results are plotted for every second day of the campaign.

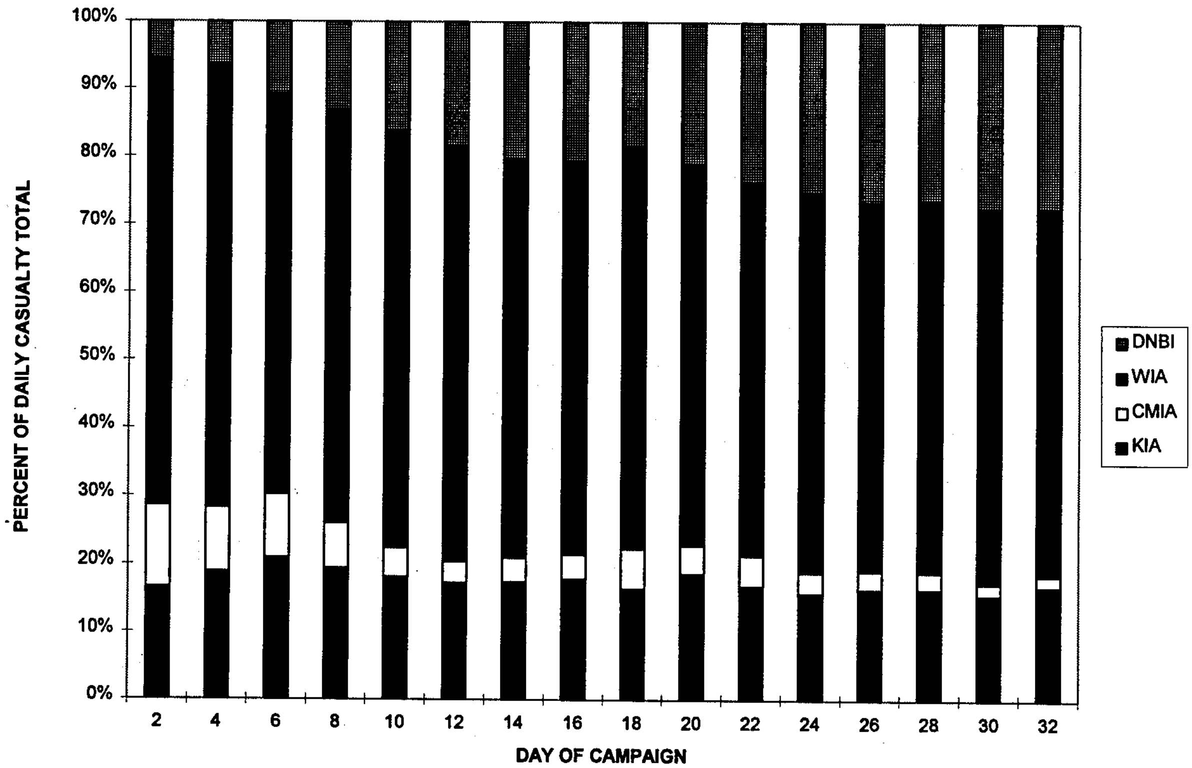


Figure H-35. Proportion of Total STOCEM Excursion Case Daily Casualties in Each Casualty Type

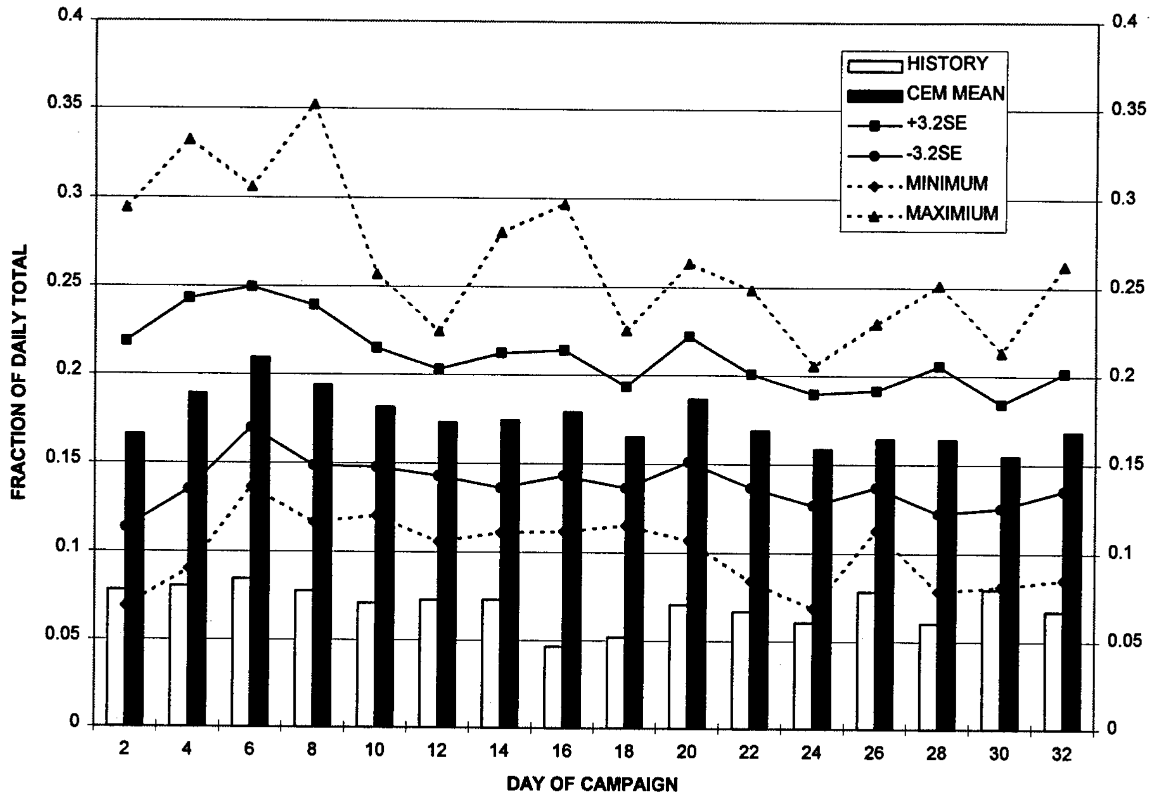


Figure H-36. Fraction KIA in Total Daily Casualties (STOCEM excursion case vs history)

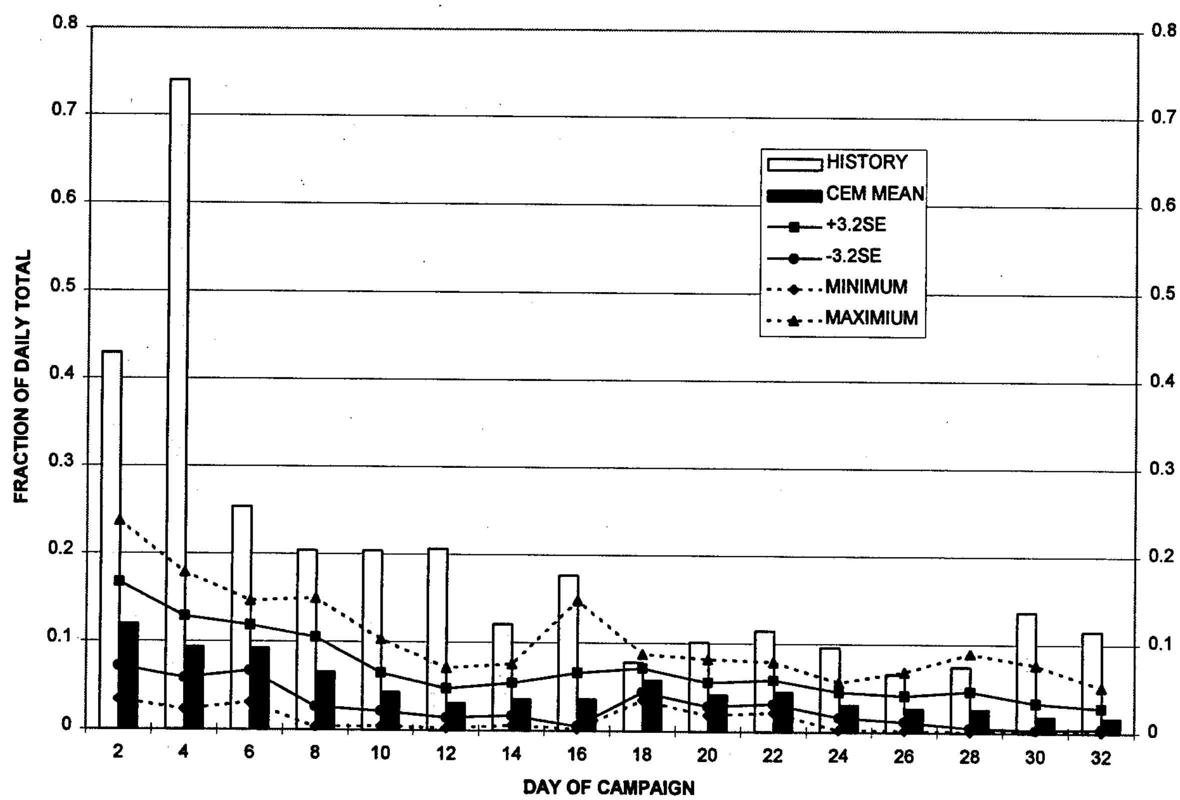


Figure H-37. Fraction CMIA in Total Daily Casualties (STOCEM excursion case vs history)

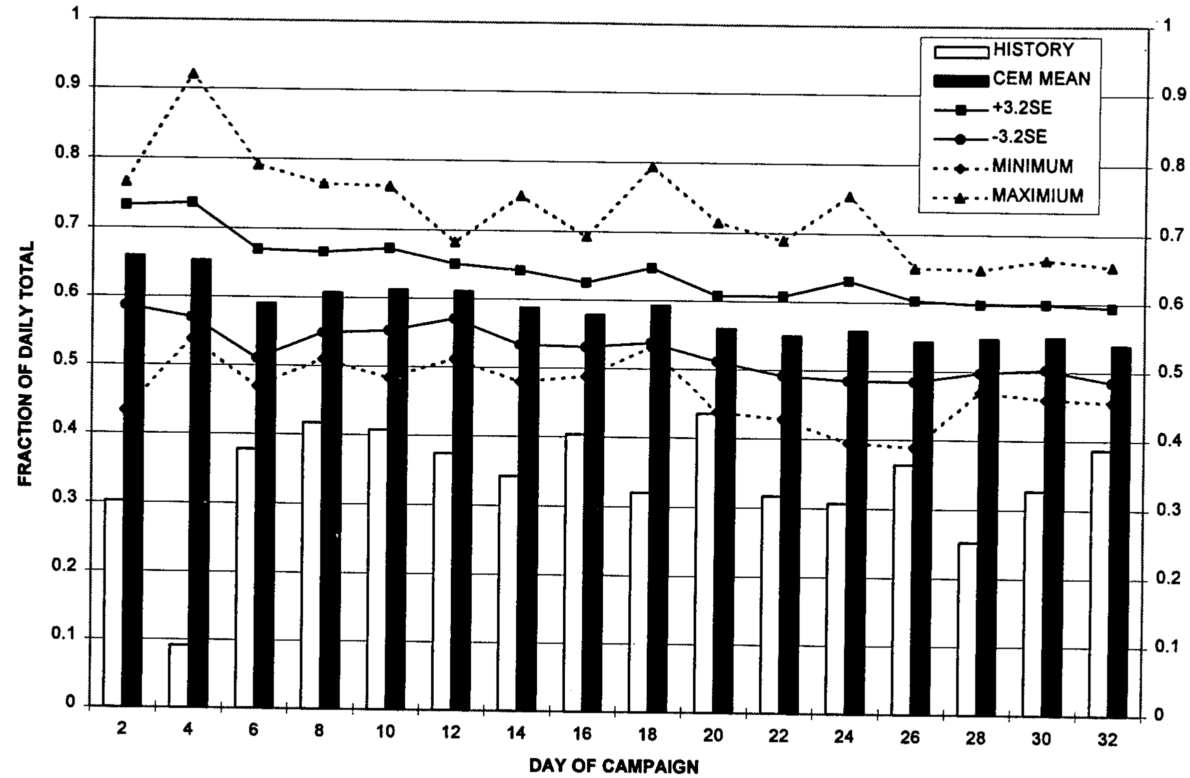


Figure H-38. Fraction WIA in Total Daily Casualties (STOCEM excursion case vs history)

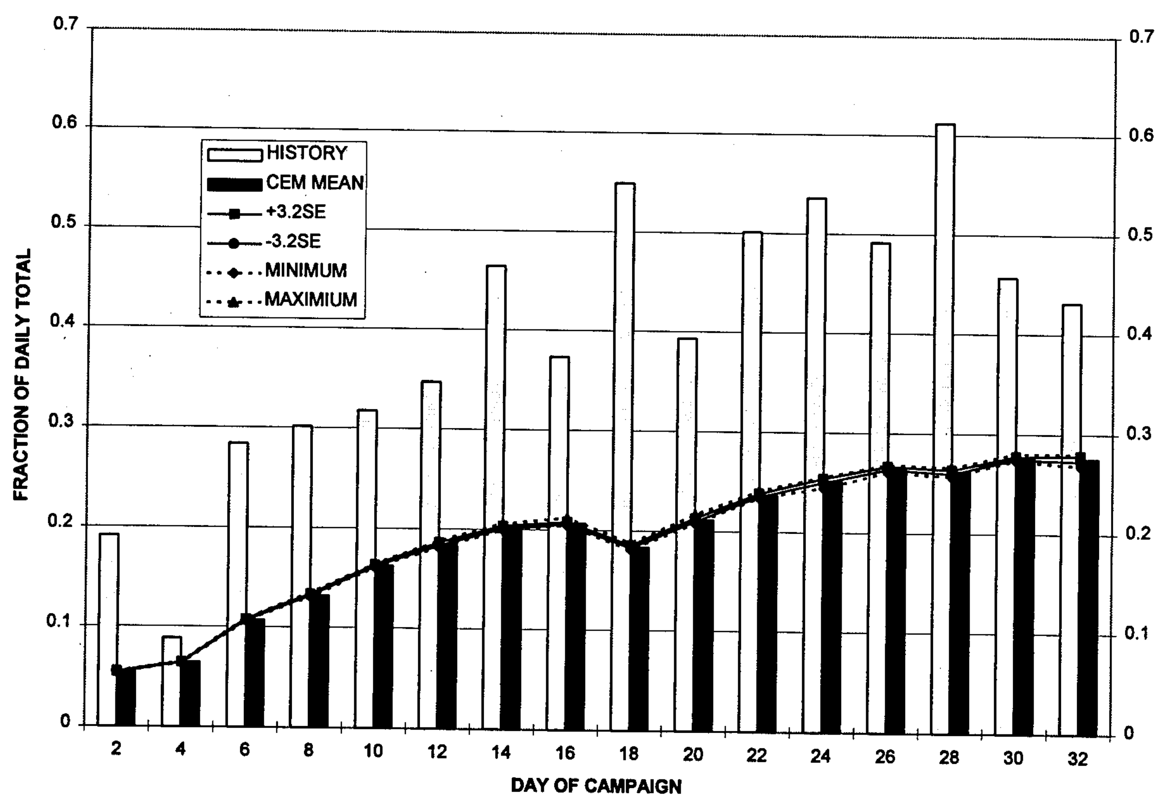
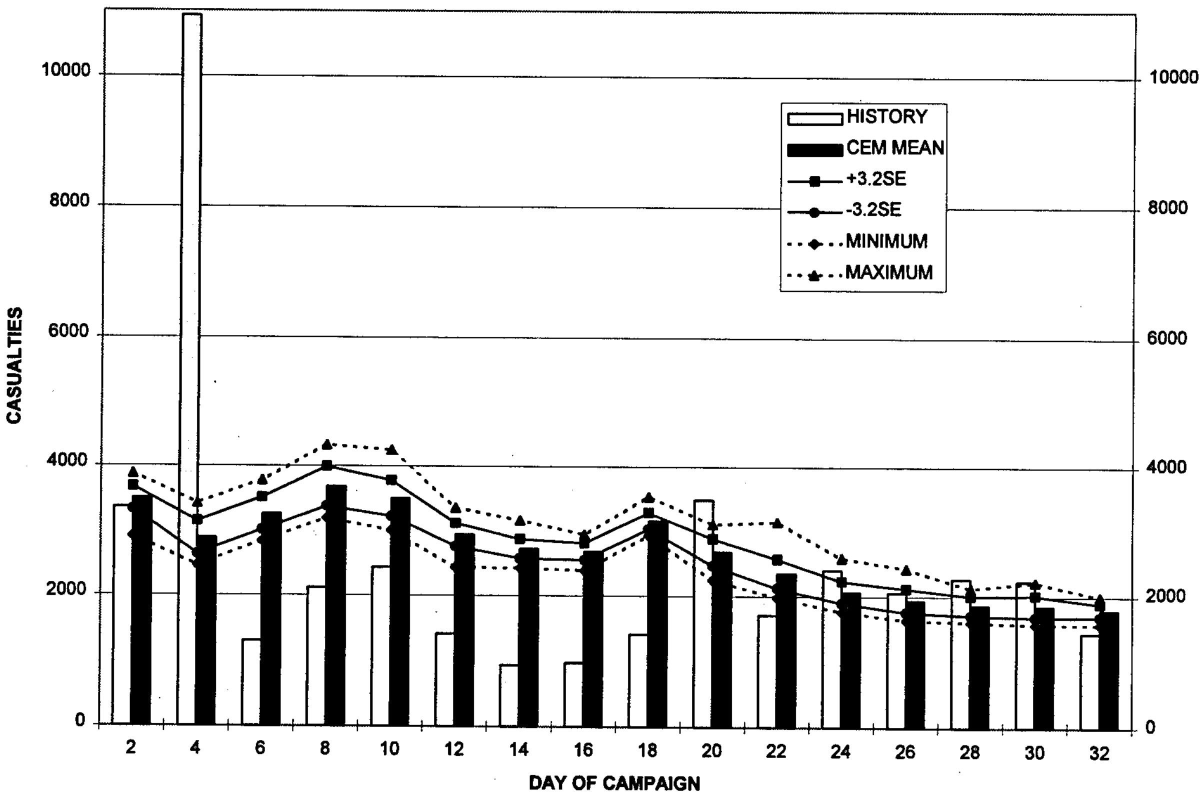
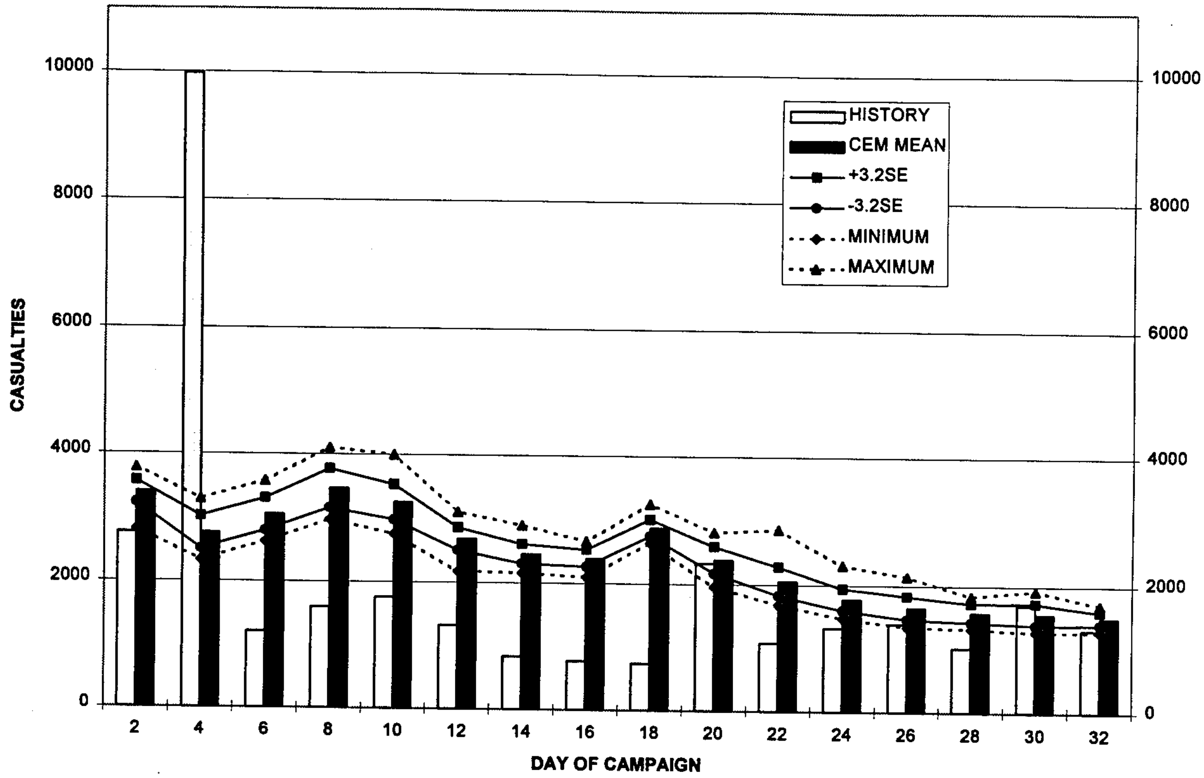


Figure H-39. Fraction DNBI in Total Daily Casualties (STOCEM excursion case vs history)

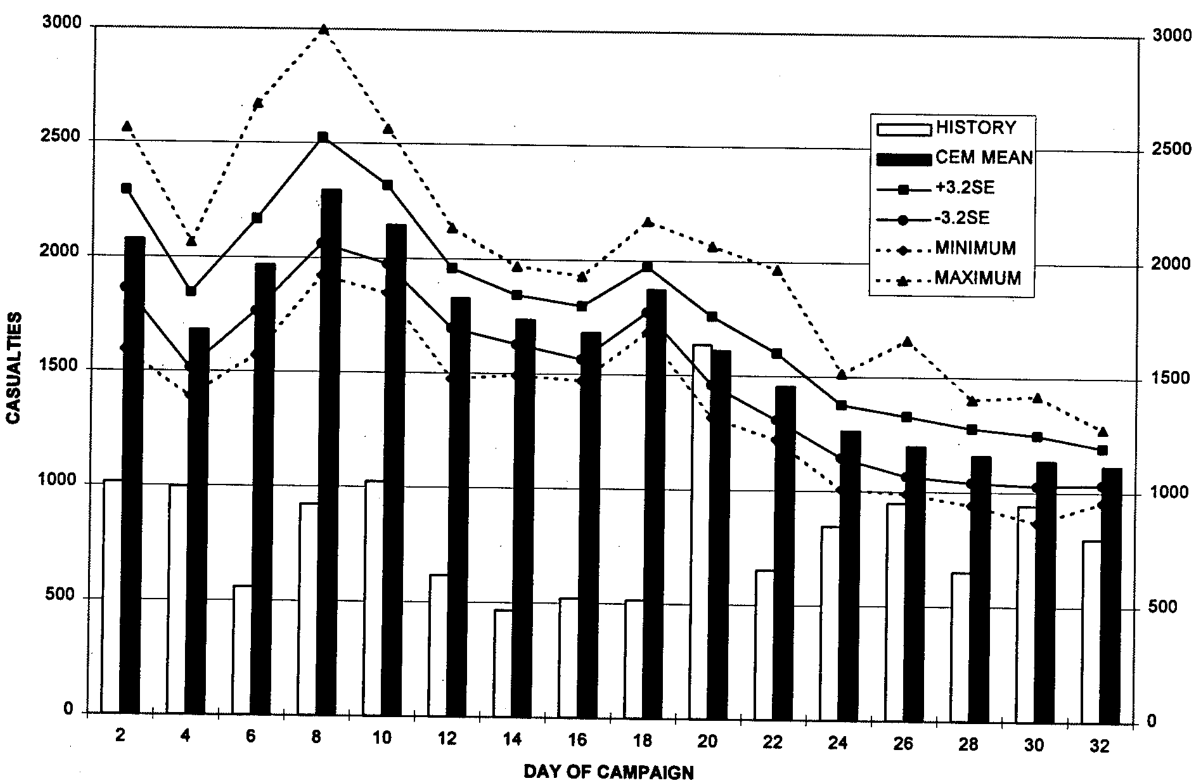
H-11. BASE CASE DAILY PERMANENT CASUALTIES. Figures H-40 through H-43 compare estimated historical daily permanent casualties with STOCEM base case daily permanent casualties for each casualty type and for selected combinations of casualty types. The figures include only casualties in the line units available for commitment to the campaign in the ARCAS scenario, as reflected in Table 2-2. The casualty types counted in the chart are identified in the title of each figure. Permanent casualties are defined and caveated in paragraph H-4. Results are plotted for every second day of the campaign.



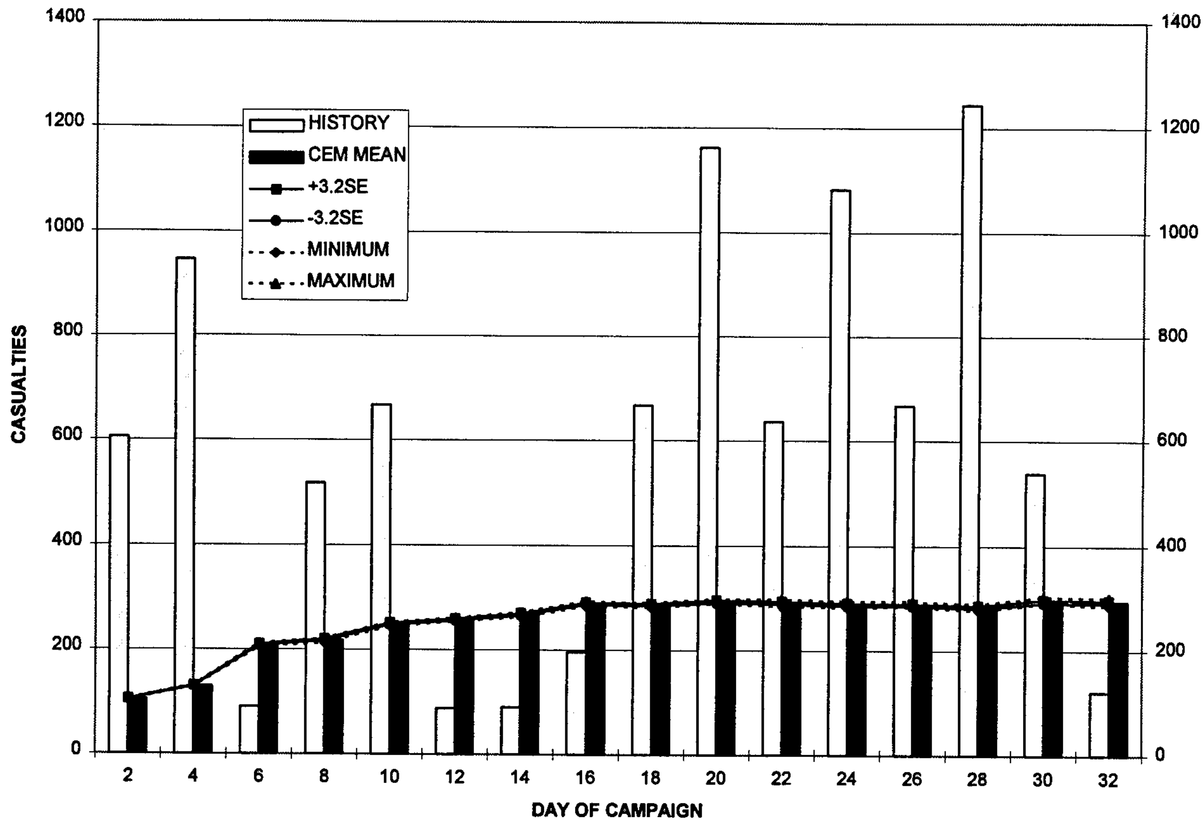
H-40. US/UK Daily Permanent Casualties (base case): KCMIA + Permanent WIA and DNBI



H-41. US/UK Daily Permanent Combat Casualties (base case): KCMIA + Permanent WIA

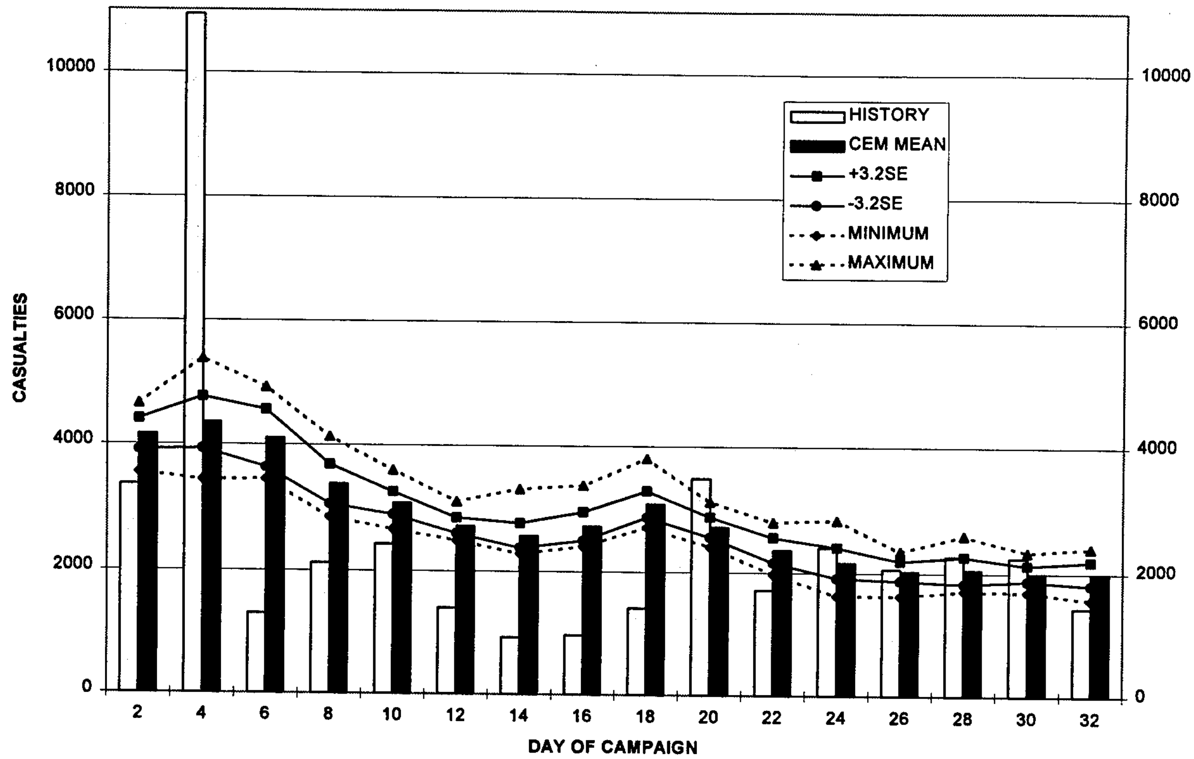


H-42. US/UK Daily Permanent WIA (base case)

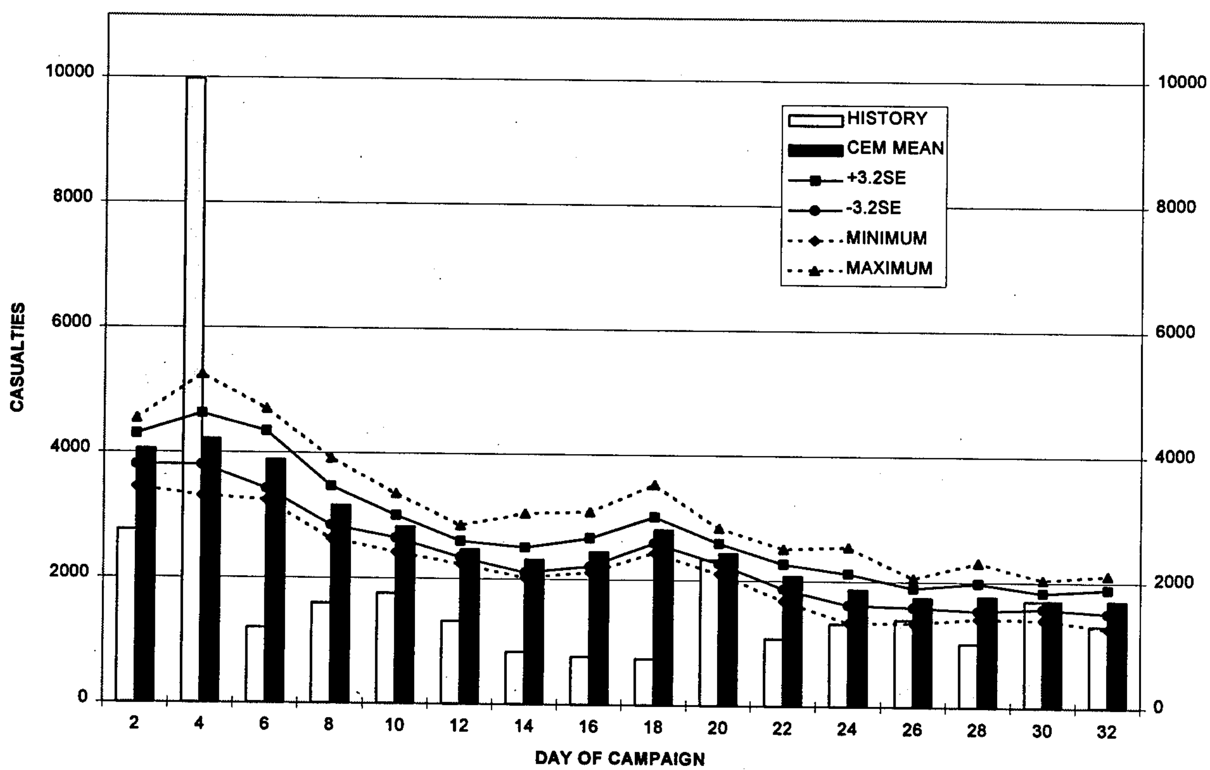


H-43. US/UK Daily Permanent DNBI (base case)

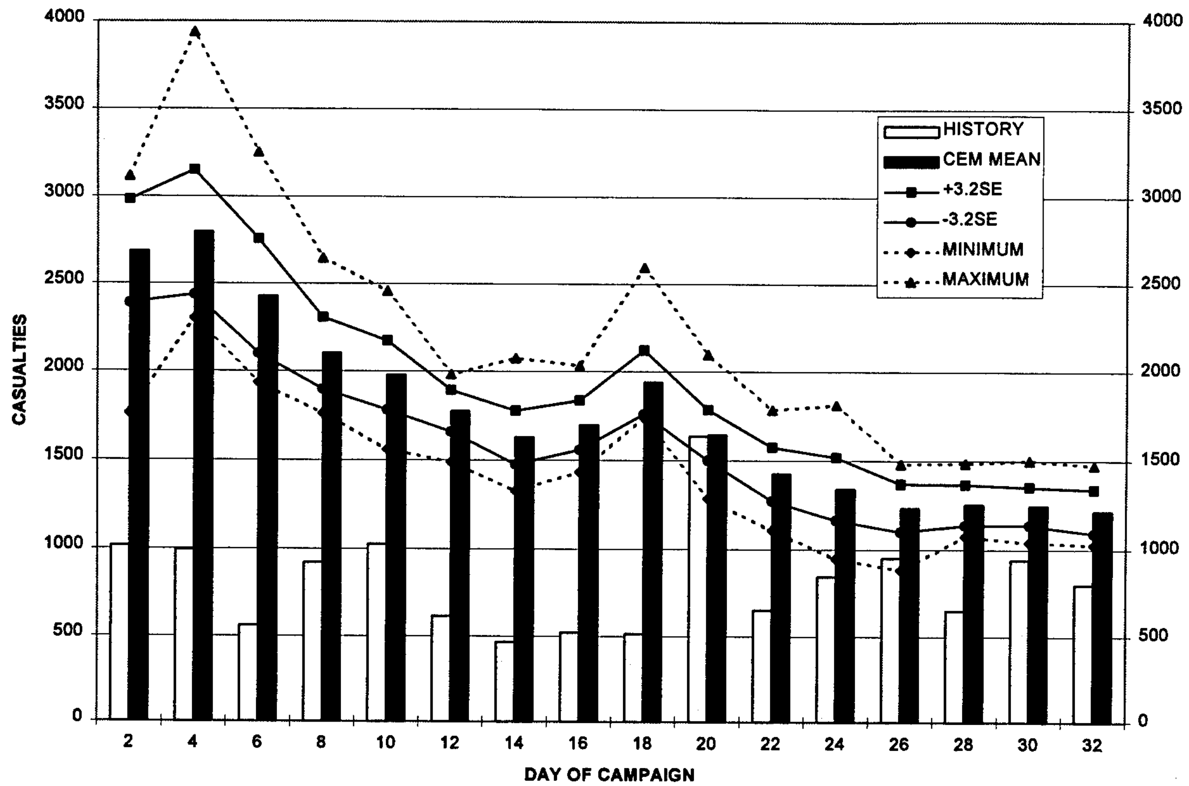
H-12. EXCURSION CASE DAILY PERMANENT CASUALTIES. Figures H-44 through H-47 compare historical daily permanent casualties with STOCEM excursion case daily permanent casualties for each casualty type and for selected combinations of casualty types. (Historical casualties in these figures are identical with historical casualties in the base case.) The figures include only casualties in the line units available for commitment to the campaign in the ARCAS scenario, as reflected in Table 2-2. Permanent casualties are defined and caveated in paragraph H-4. Results are plotted for every second day of the campaign.



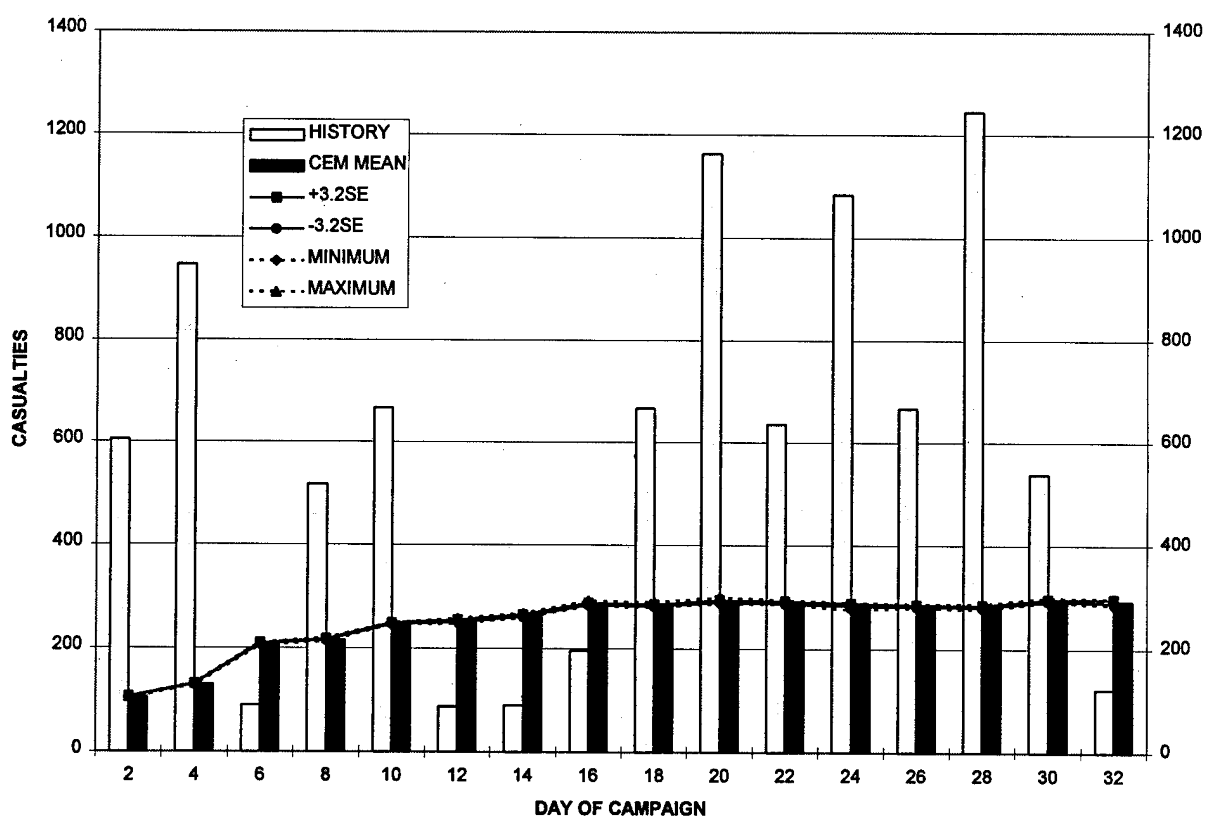
H-44. US/UK Daily Permanent Casualties (excursion case): KCMIA + Permanent WIA and DNBI



H-45. US/UK Daily Permanent Combat Casualties (excursion case): KCMIA + Permanent WIA and DNBI

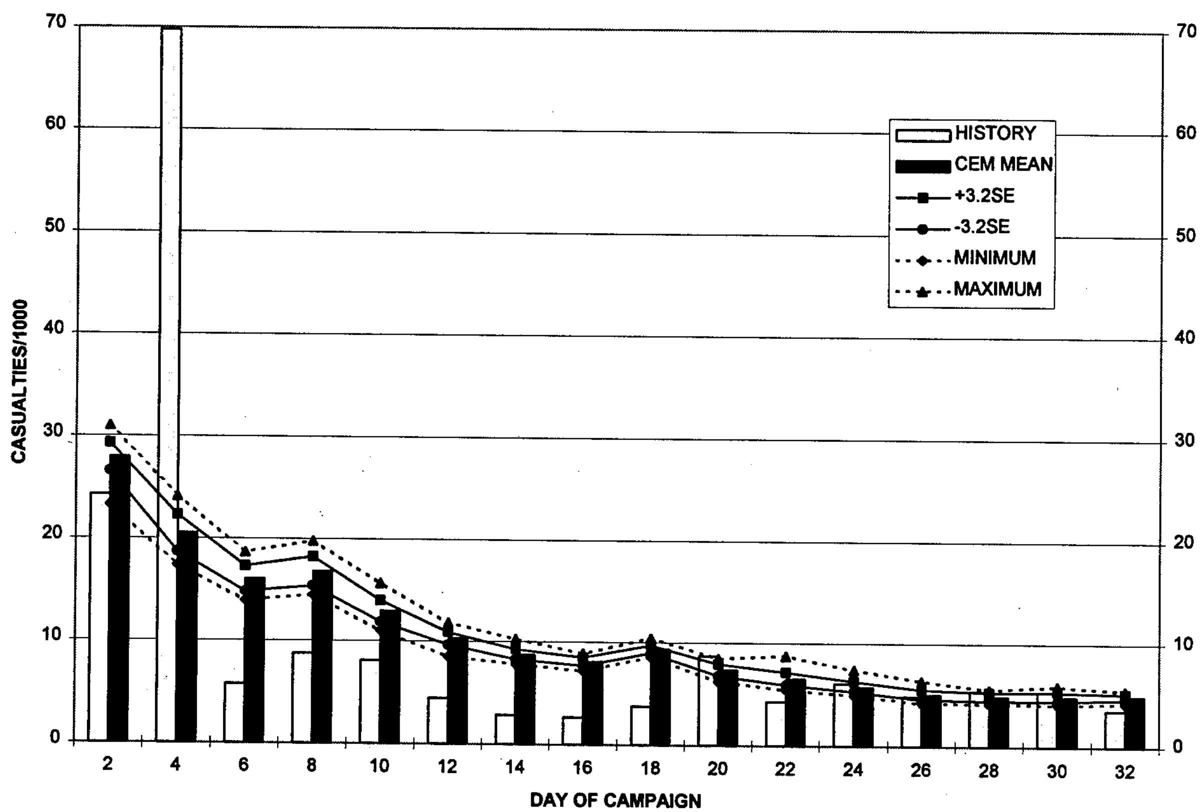


H-46. US/UK Daily Permanent WIA (excursion case)

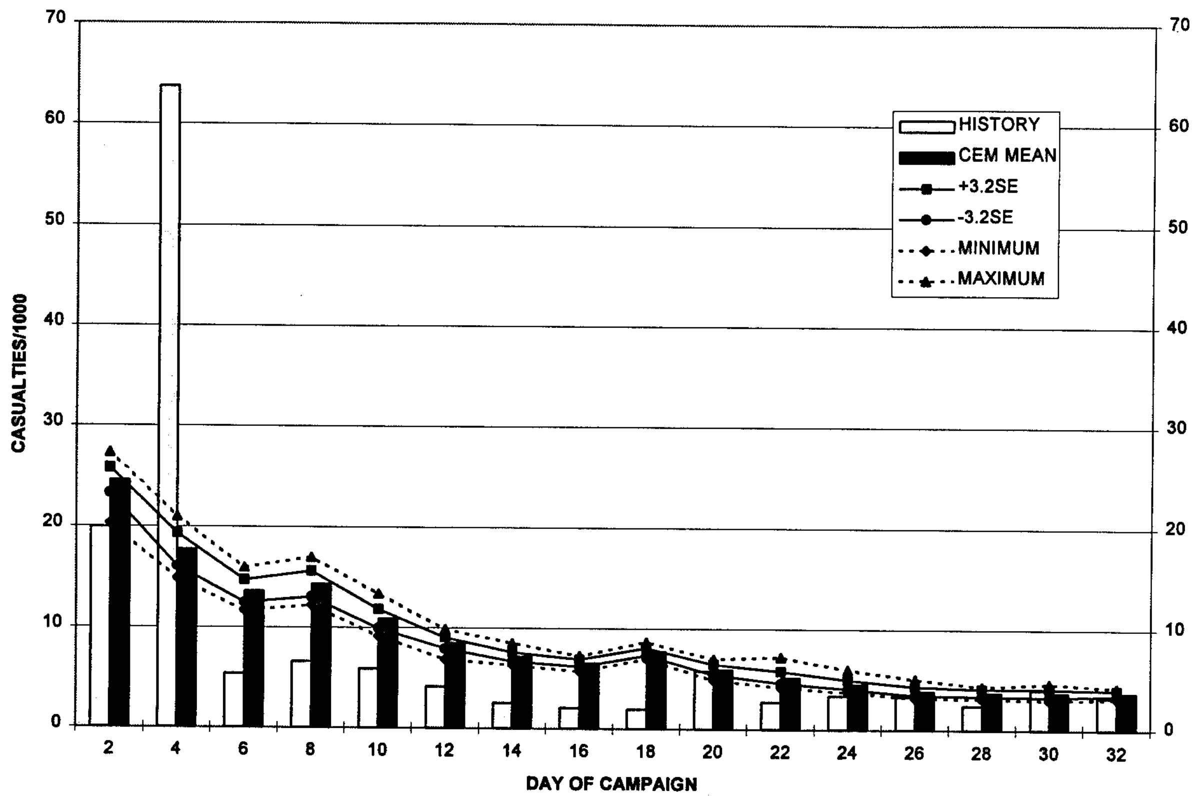


H-47. US/UK Daily Permanent DNBI (excursion case)

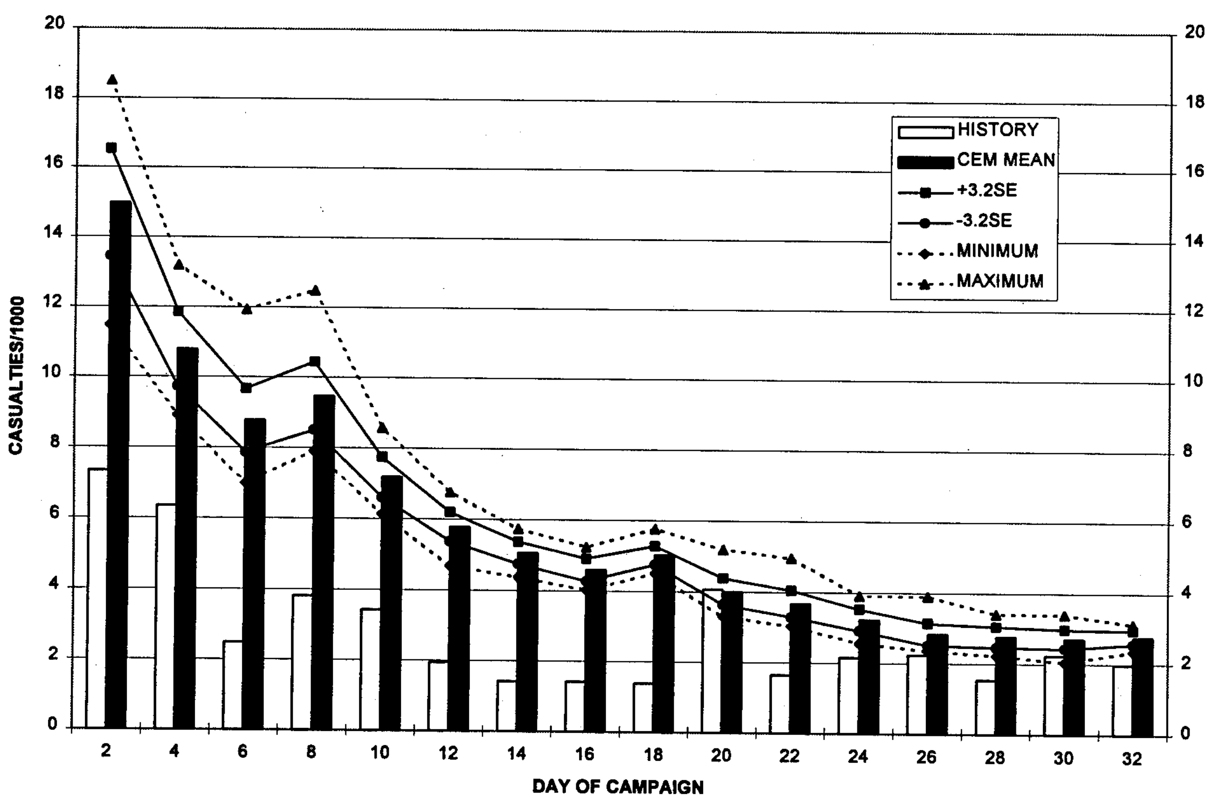
H-13. STOCEM BASE CASE DAILY PERMANENT CASUALTY RATES. Figures H-48 through H-51 compare estimated historical daily permanent casualty rates with STOCEM base case daily permanent casualty rates for each casualty type and for selected combinations of casualty types. Casualty rates are expressed as permanent casualties per thousand onhand personnel in the line units available for commitment to the campaign. The casualty types included in the results portrayed are identified in the title of each figure. The figures include only casualties in the line units available for commitment to the campaign in the ARCAS scenario, as reflected in Table 2-2. Permanent casualties are defined and caveated in paragraph H-4. Results are plotted for every second day of the campaign.



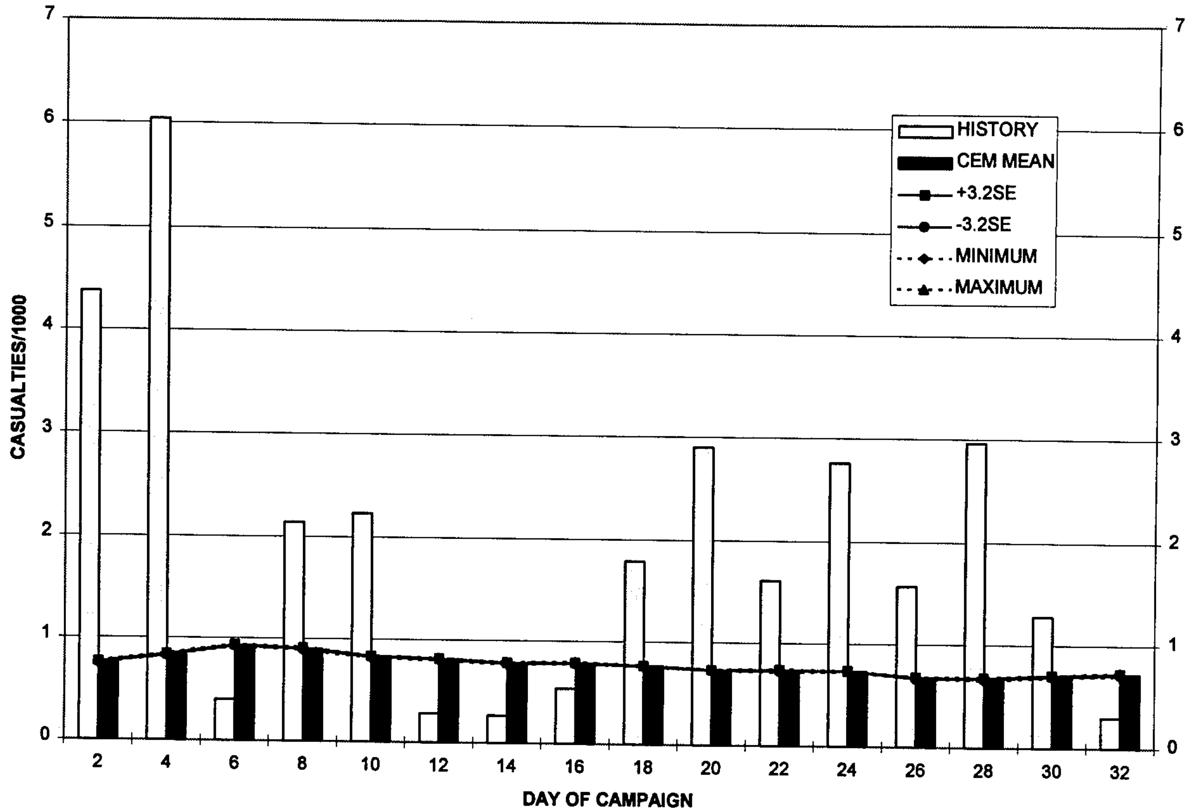
H-48. US/UK Daily Permanent Casualty Rate (base case): KCMIA + Permanent WIA and DNBI



H-49. US/UK Daily Permanent Combat Casualty Rate (base case): KCMIA + Permanent WIA

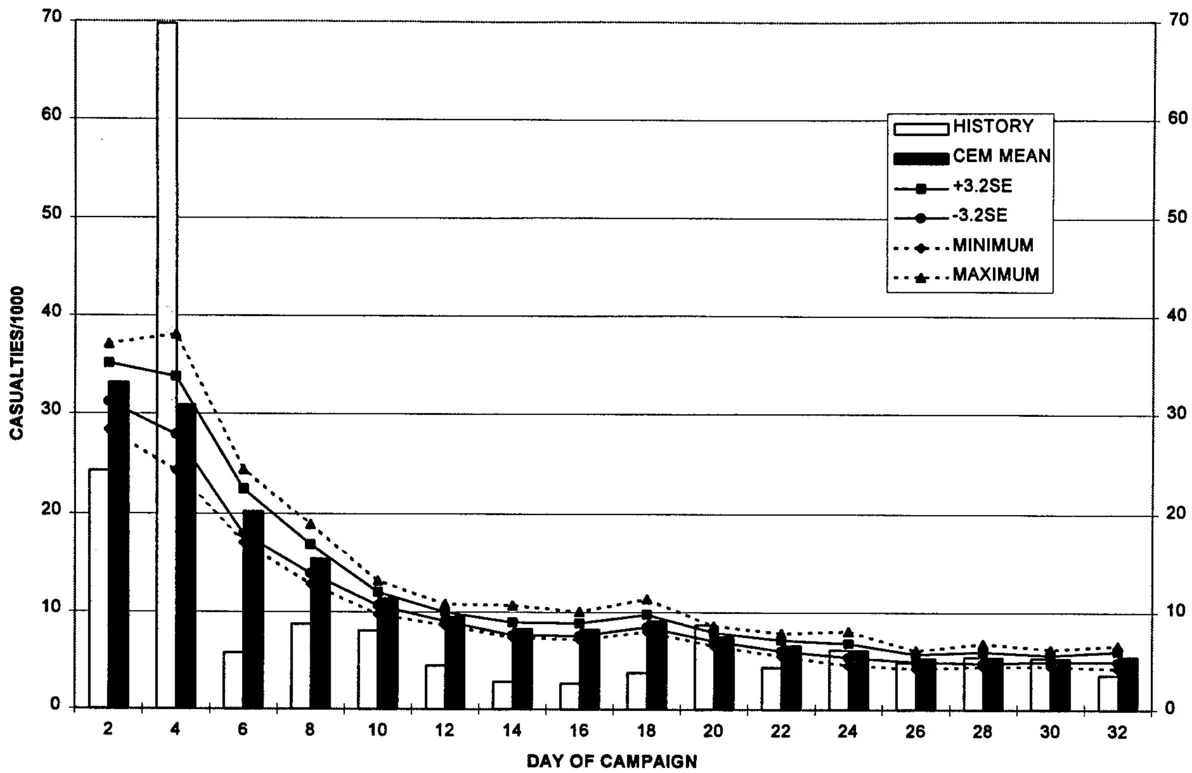


H-50. US/UK Daily Permanent WIA Rate (base case)

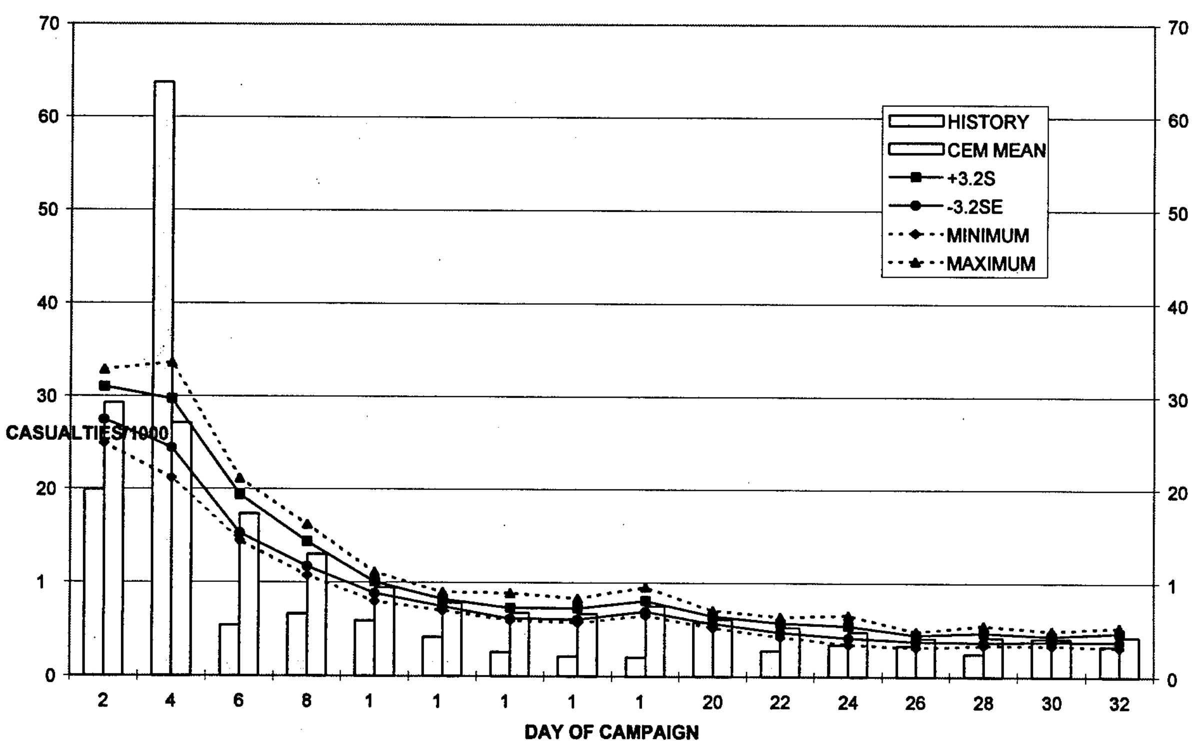


H-51. US/UK Daily Permanent DNBI (base case)

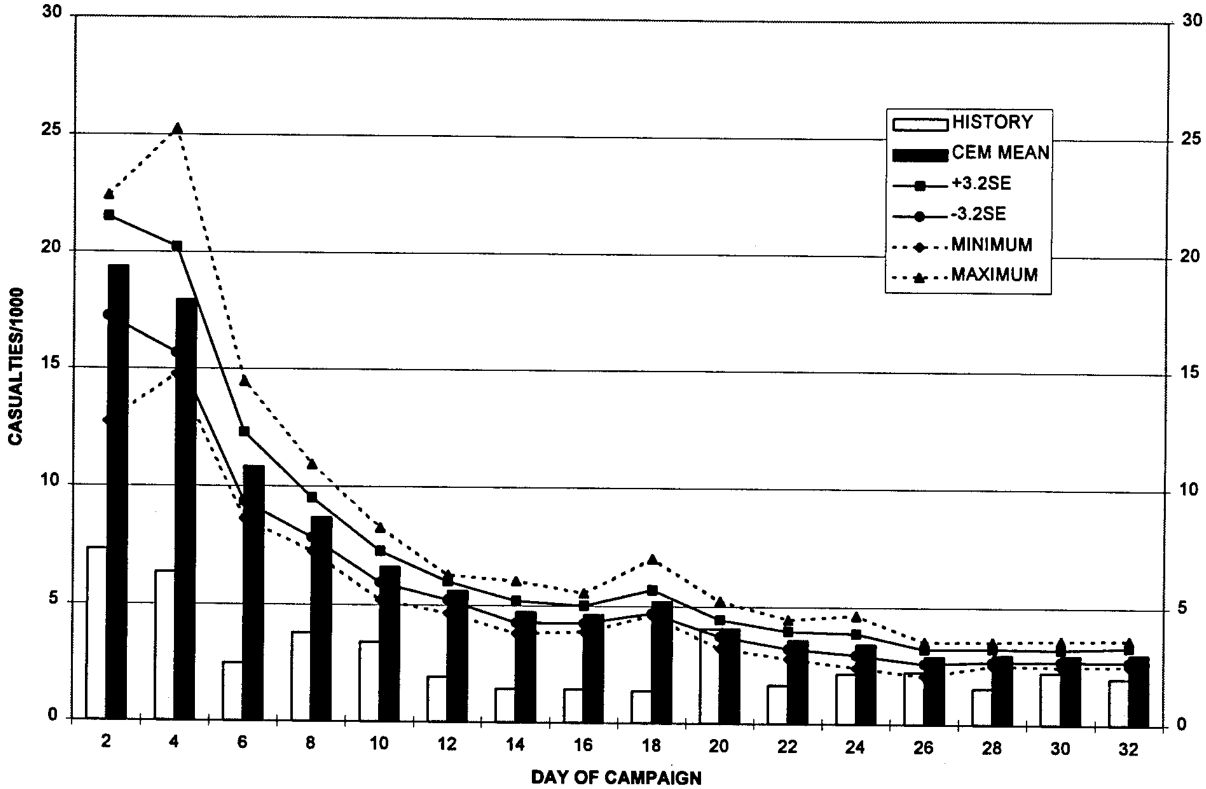
H-14. STOCEM EXCURSION CASE DAILY PERMANENT CASUALTY RATES. Figures H-52 through H-55 compare estimated historical daily permanent casualty rates with STOCEM excursion case daily permanent casualty rates for each casualty type and for selected combinations of casualty types. Casualty rates are expressed as permanent casualties per thousand onhand personnel in the line units available for commitment to the campaign. The casualty types included in the results portrayed are identified in the title of each figure. (Historical casualties in these figures are identical with historical casualties in the base case.) The figures include only casualties in the line units available for commitment to the campaign in the ARCAS scenario, as reflected in Table 2-2. Permanent casualties are defined and caveated in paragraph H-4. Results are plotted for every second day of the campaign.



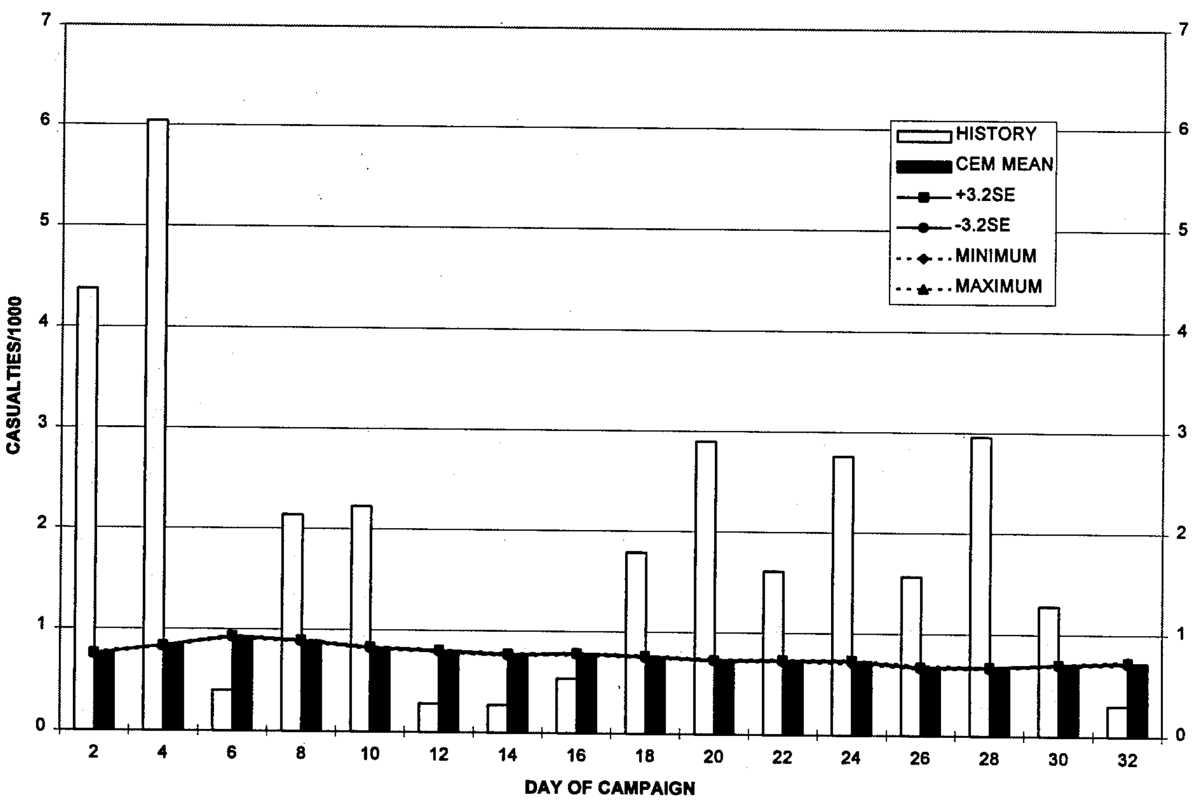
H-52. US/UK Daily Permanent Casualty Rate (excursion case): KCMIA + Permanent WIA and DNBI



H-53. US/UK Daily Permanent Combat Casualty Rate (excursion case): KCMIA + Permanent WIA

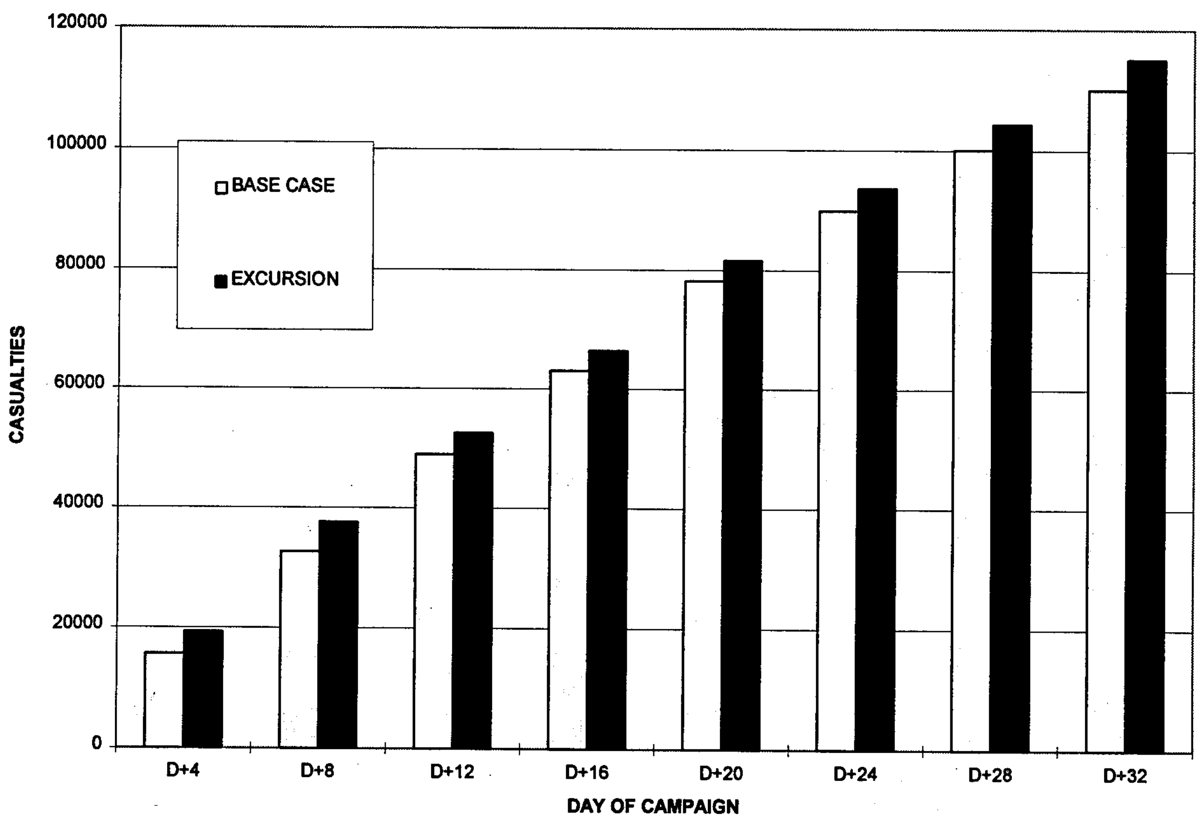


H-54. US/UK Daily Permanent WIA Rate (excursion case)

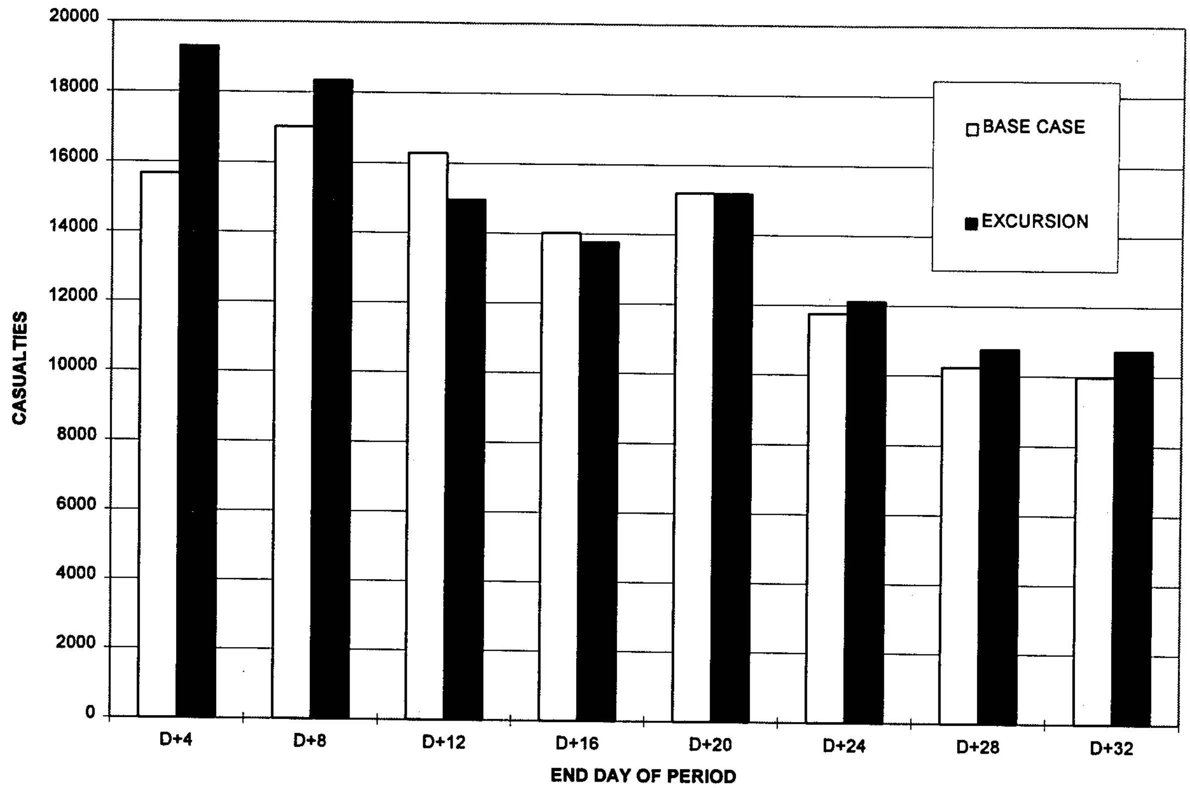


H-55. US/UK Daily Permanent DNBI (excursion case)

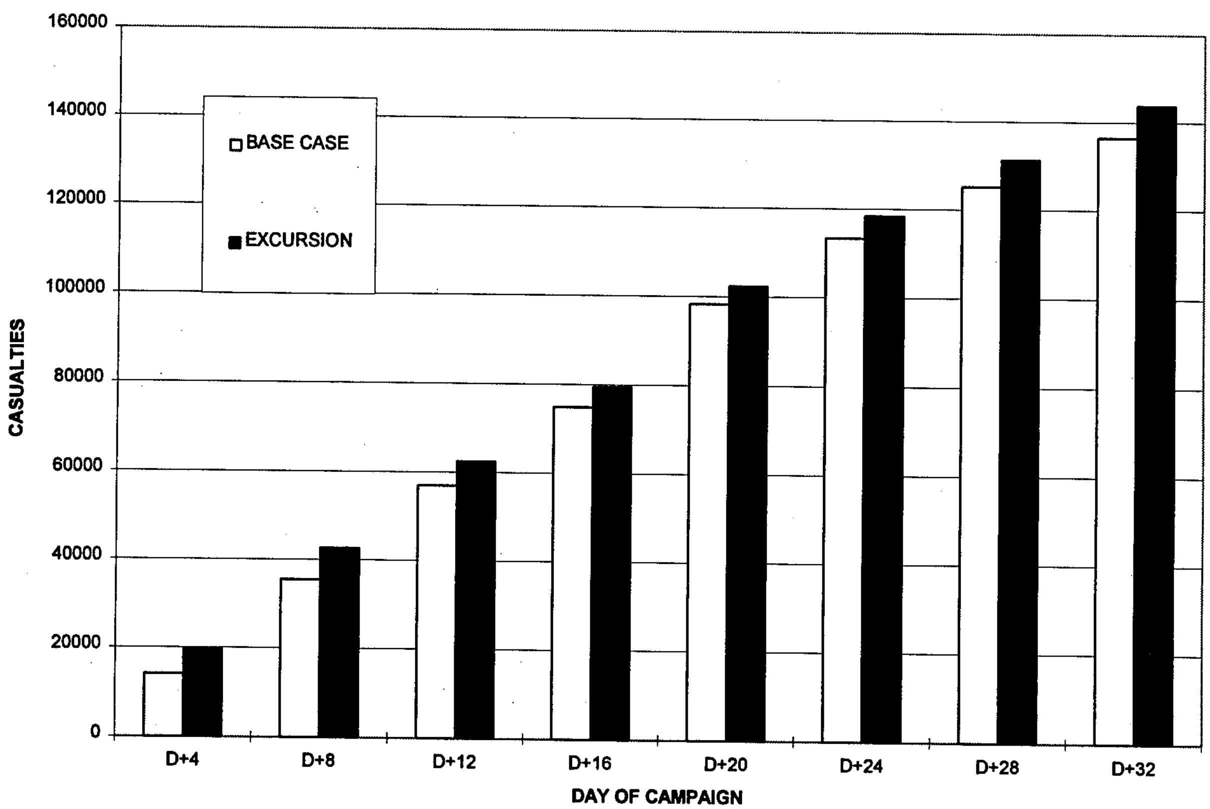
H-15. COMPARATIVE TOTAL CASUALTIES. The STOCEM base case casualties depicted in Figures 6-1 through 6-4 are compared with the corresponding excursion case results in Figures H-56 through H-59. Figures H-56 and H-58 compare total STOCEM base case cumulative casualties with total excursion case cumulative casualties for the US/UK and the German force, respectively. Figures H-57 and H-59 compare total STOCEM base case casualties in each 4-day period with total excursion case casualties in each 4-day periods for the US/UK and the German force, respectively. The figures include only casualties in the line units available for commitment to the campaign in the ARCAS scenario, as reflected in Table 2-2. The casualty types counted in the chart are identified in the title of each figure.



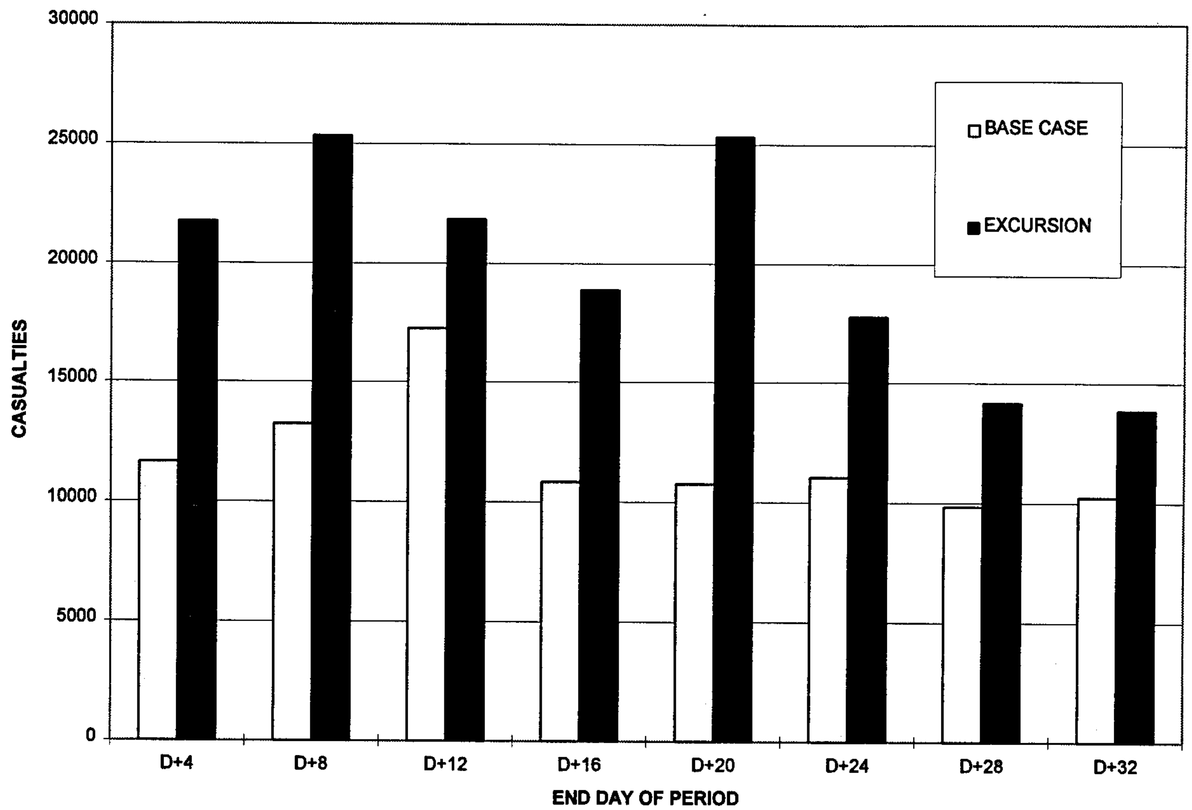
H-56. Cumulative STOCEM US/UK Personnel Losses (base case vs excursion)



H-57. STOCEM US/UK Personnel Losses in Each 4-day Period (base case vs excursion)



H-58. Cumulative STOCEM German Personnel Losses (base case vs excursion)



H-59. STOCEM German Personnel Losses in Each 4-day Period (base case vs excursion)

H-16. COMPARATIVE TOTAL BASE CASE CASUALTIES BY CASUALTY TYPE. Figures H-60 through H-63 show base case STOCEM and historical cumulative (since D-day) total US/UK personnel casualties in each casualty type at 4-day intervals. These figures partition the casualty results shown in Figure 6-1 into the four casualty type components (KIA, CMIA, WIA, DNBI). Figures H-64 through H-67 show base case STOCEM and historical total US/UK personnel casualties in each casualty type during each 4-day period. These figures partition the casualty results shown in Figure 6-2 into the four casualty type components.

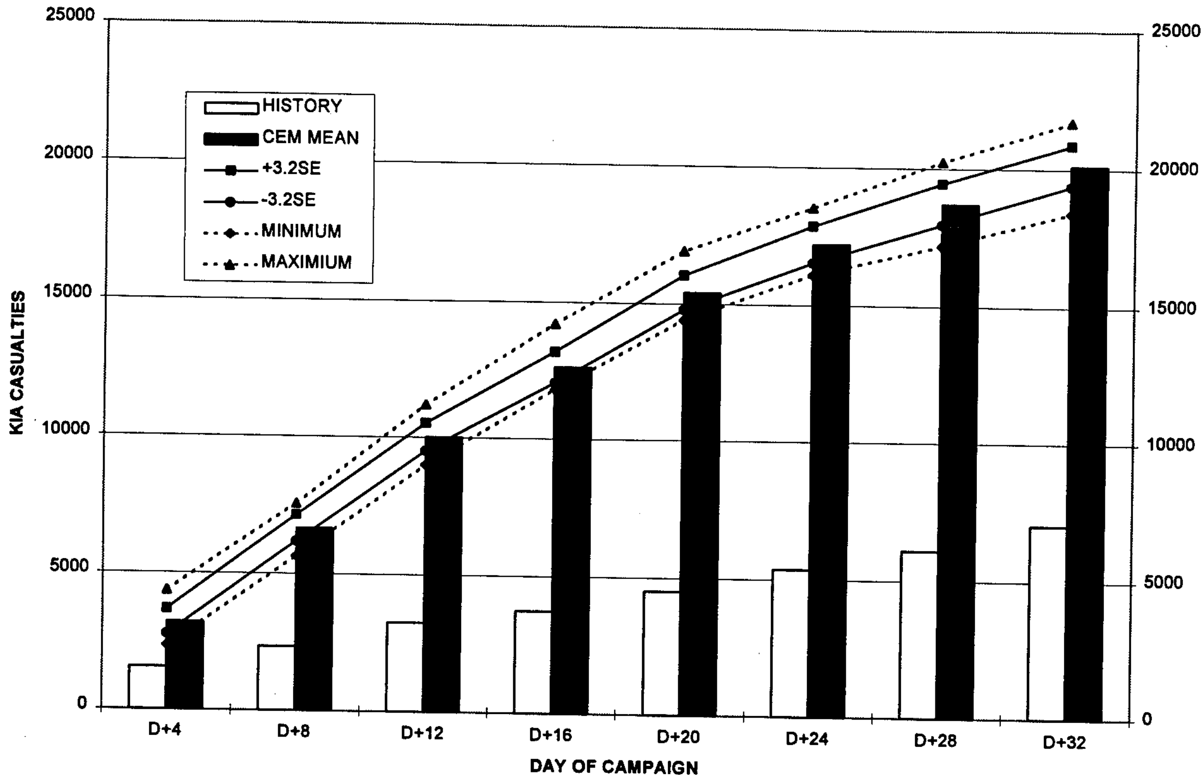


Figure H-60. Cumulative US/UK KIA Casualties (history vs STOCEM base case)

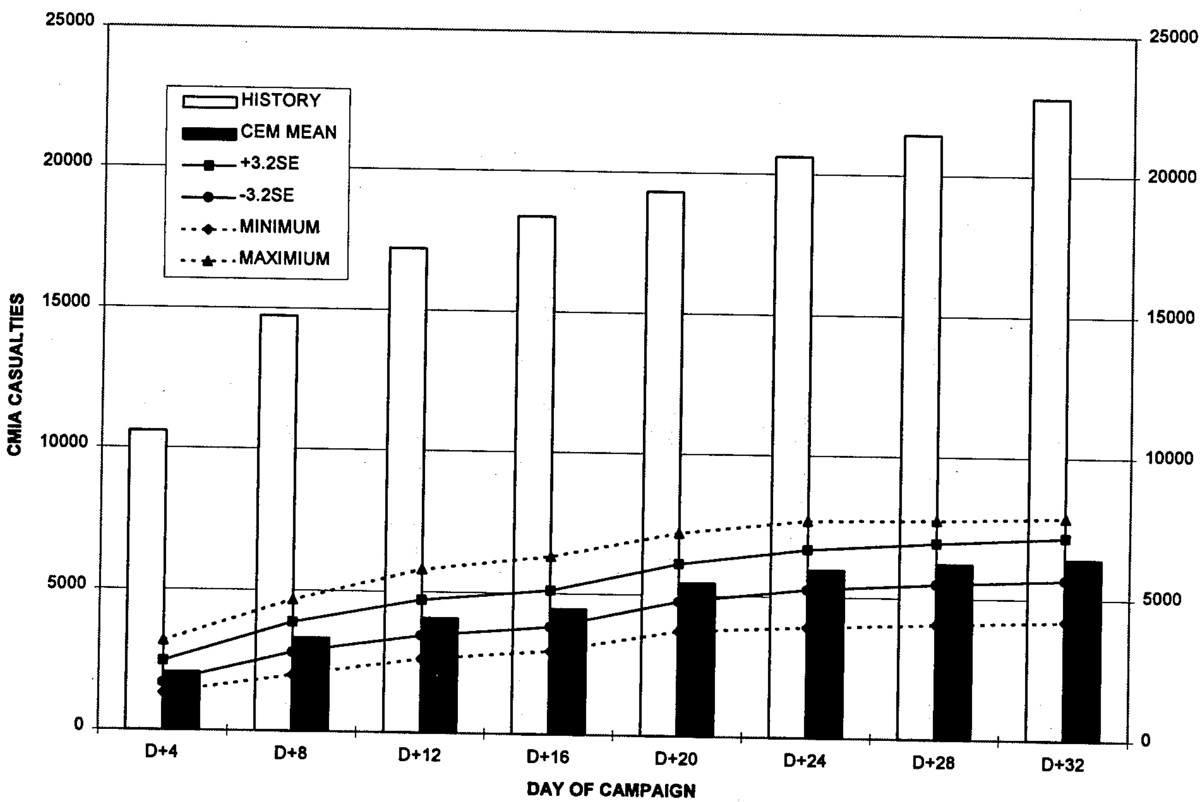


Figure H-61. Cumulative US/UK CMIA Casualties (history vs STOCEM base case)

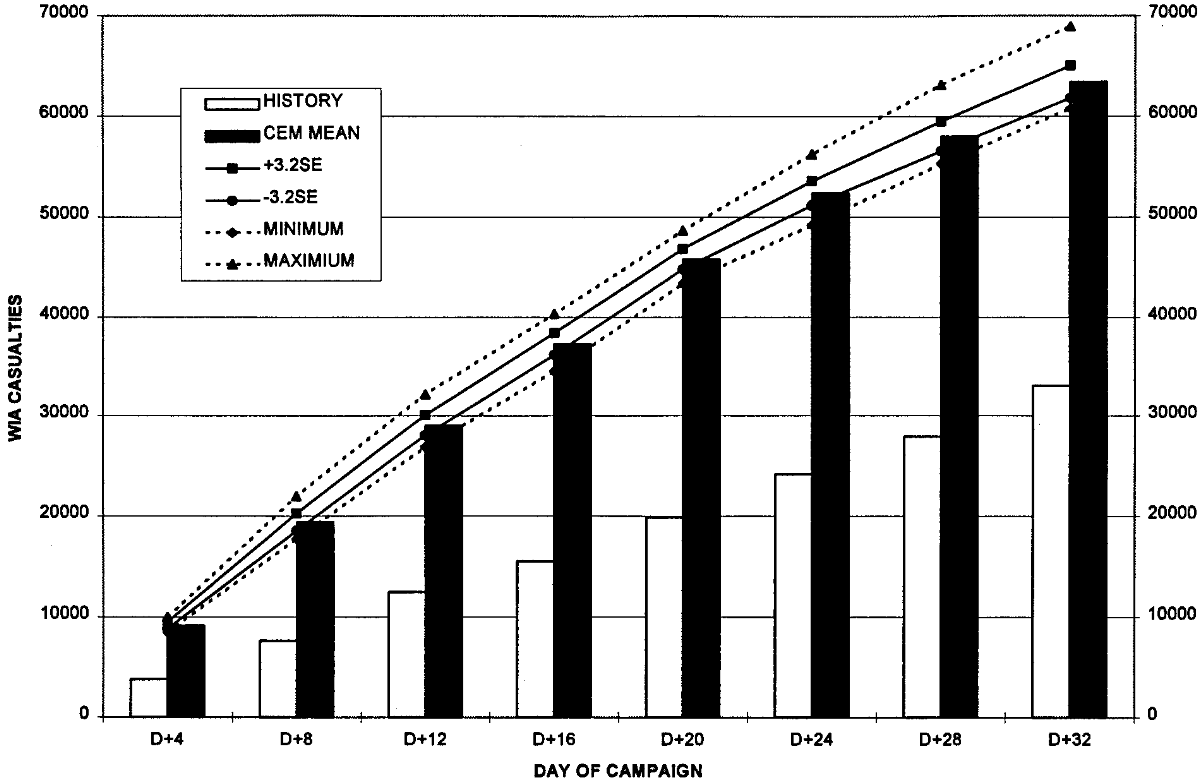


Figure H-62. Cumulative US/UK WIA Casualties (history vs STOCEM base case)

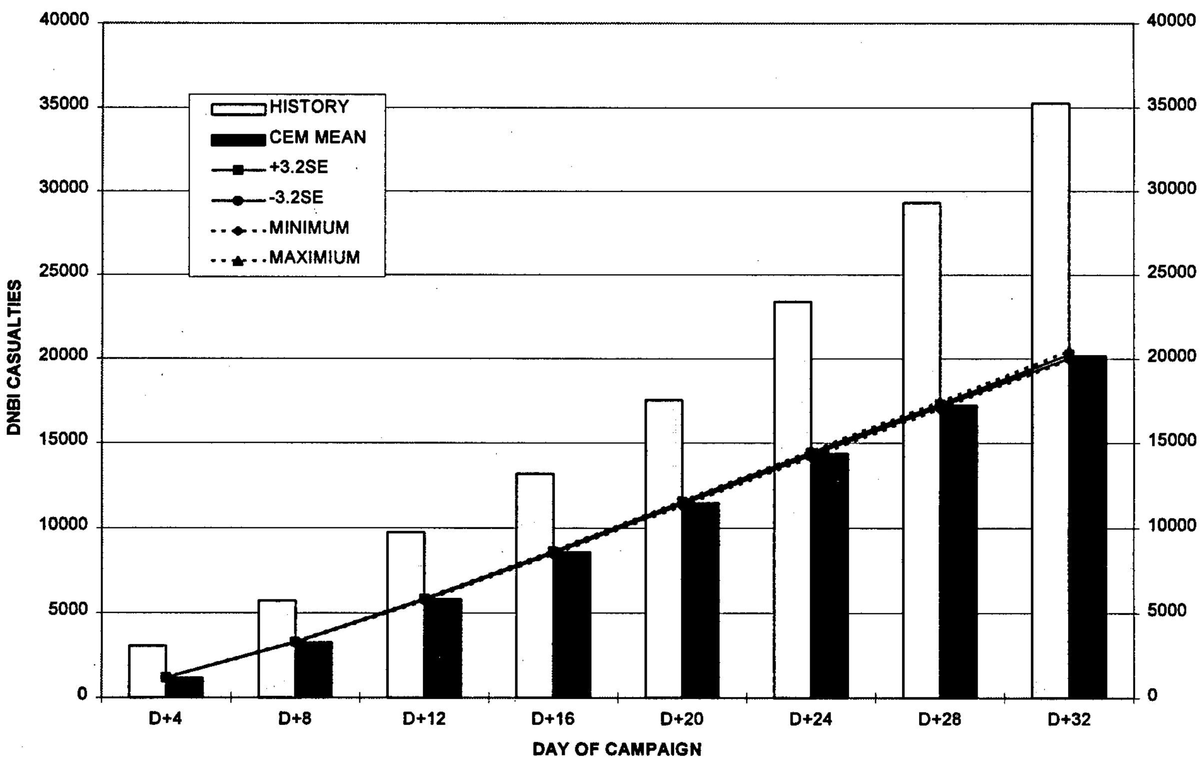


Figure H-63. Cumulative US/UK DNBI Casualties (history vs STOCEM base case)

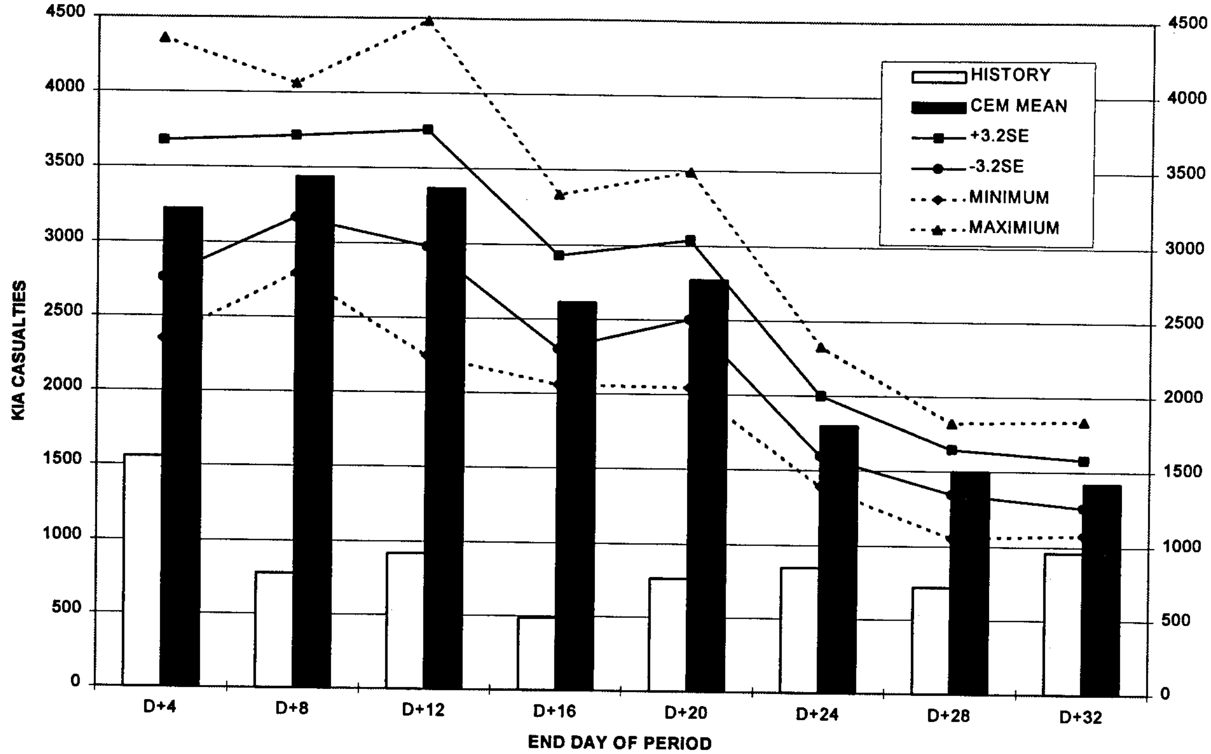


Figure H-64. US/UK KIA Casualties in Each 4-day Period (history vs STOCEM base case)

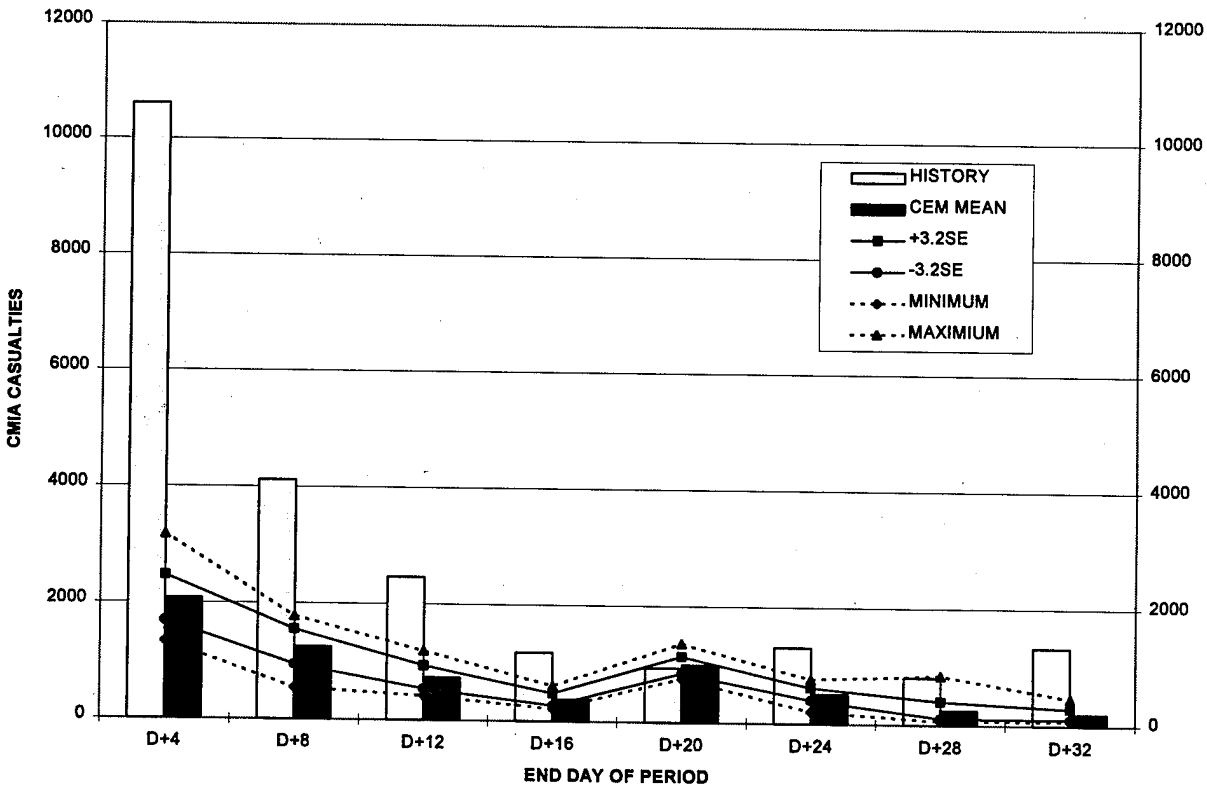


Figure H-65. US/UK CMIA Casualties in Each 4-day Period (history vs STOCEM base case)

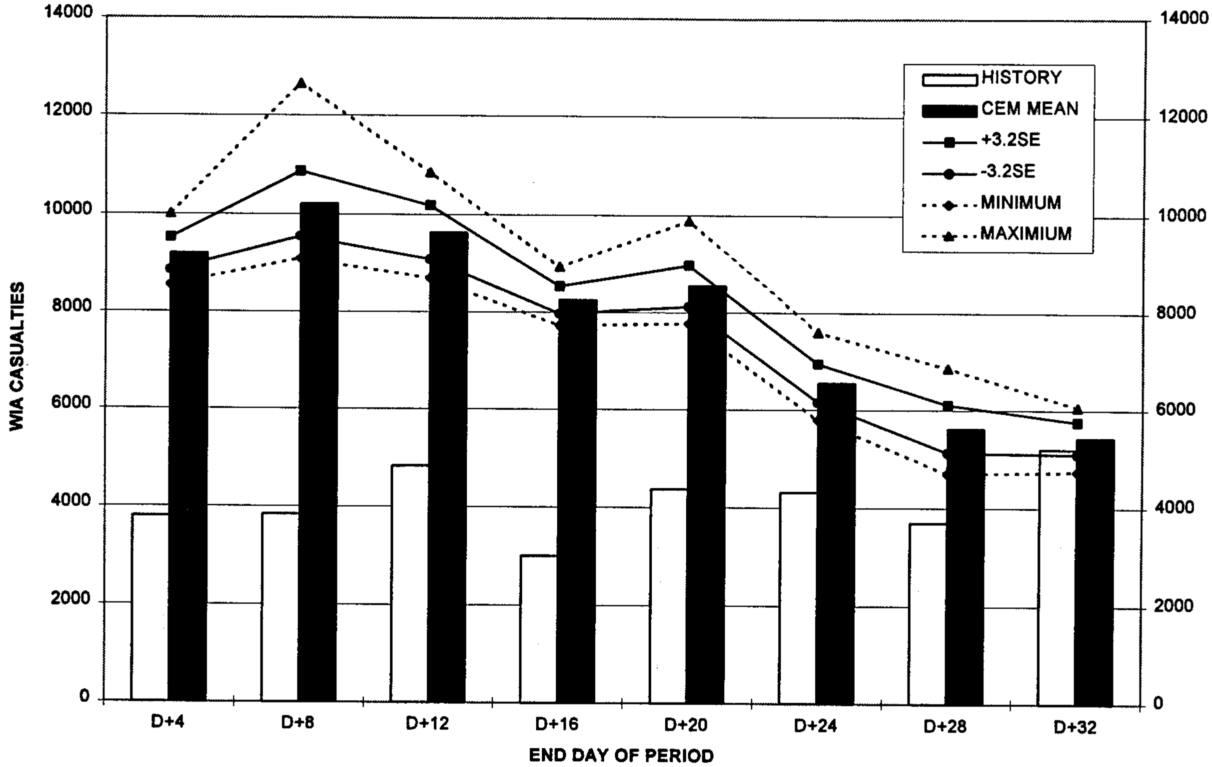


Figure H-66. US/UK WIA Casualties in Each 4-day Period (history vs STOCEM base case)

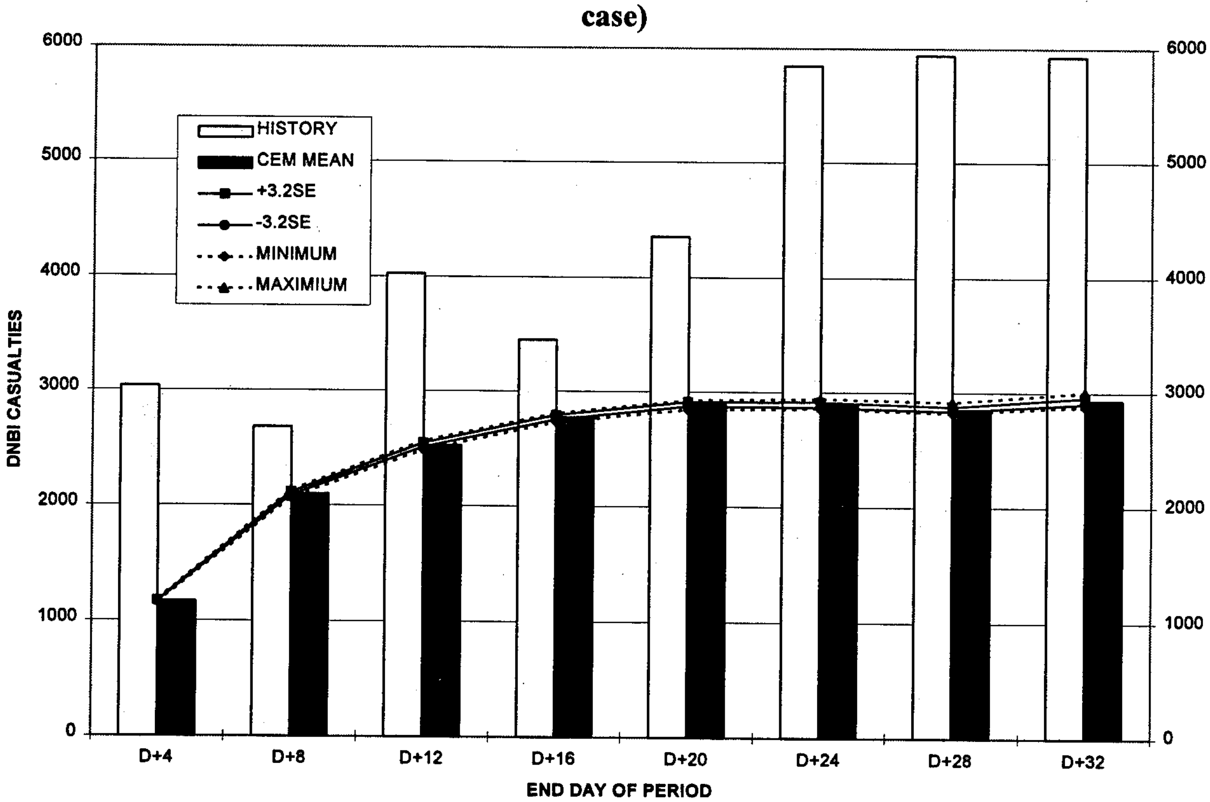


Figure H-67. US/UK DNBI Casualties in Each 4-day Period (history vs STOCEM base case)

APPENDIX I

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GLOSSARY

1. ABBREVIATIONS, ACRONYMS, AND SHORT TERMS

AbnD	airborne division
ACSDB	Ardennes Campaign Simulation Data Base
AD	armored division
APC	armored personnel carrier
AR	Army regulation
arm	armored
ARCAS	Ardennes Campaign Simulation (study)
AT/M	antitank/mortar
bde	brigade
CAA	US Army Concepts Analysis Agency
CAS	close air support
cbt	combat
CMIA	captured/missing in action
DNBI	disease and nonbattle injuries
DS	direct support
EEA	essential element(s) of analysis
FBB	Fuehrer Begleit Brigade
FEBA	forward edge of the battle area
FGB	Fuehrer Grenadier Brigade
FJD	fallschirmjaeger division
GS	general support
HERO	Historical Evaluation and Research Organization
ID	infantry division
K	corps (German)

KIA	killed in action
km	kilometer(s)
max	maximum
min	minimum
mm	millimeter(s)
MOE	measure(s) of effectiveness
MOS	military occupational specialty
PzArmy	panzer army
PzBde	panzer brigade
PzGD	panzer grenadier division
PzD	panzer division
PzK	panzer corps
PzLehrD	(Lehr) Panzer Division
Ref.	Reference
STC	Shape Technical Centre
TOE	table(s) of organization and equipment
US	United States
UK	United Kingdom
VGD	volks grenadier division
V&V	verification and validation
WIA	wounded in action
wpn	weapon
WW II	World War II

2. TERMS UNIQUE TO THIS STUDY

avenue of advance

One of a series of movement corridors corresponding to the initially planned flow of forces in CEM during the modeled campaign. These avenues are serially indexed from north to south and provide a way of representing FEBA progress on a Cartesian coordinate system (as km progress in each avenue).

base case

The STOCEM representation of the Ardennes Campaign, based on initial conditions from the ACSDB, in which each reinforcing unit, on both sides, is assigned to the army area of operations which it historically supported.

Base History (FEBA)

The (line connecting the) average ACSDB location of the westernmost 40 percent of the German ACSDB unit location points on (i.e., closest to) each STOCEM avenue of advance. The Base History FEBA is used as the "standard" historical FEBA derived from the ACSDB.

excursion case

A STOCEM representation of the Ardennes Campaign which is identical to the ARCAS base case, except that each reinforcing unit is assigned to a sector of operations chosen by STOCEM logic, based on force ratios of opposing units.

Hi History (FEBA)

The (line connecting the) single westernmost German ACSDB unit reference point on (i.e., closest to) each STOCEM avenue of advance. This measure is used as an estimator of the upper bound (maximum advance) of the History FEBA.

Lo History (FEBA)

The (line connecting the) average ACSDB location of all of the German ACSDB unit reference points on (i.e., closest to) each STOCEM avenue of advance. This measure is used as an estimator of the lower bound (minimum advance) of the History FEBA.

+-3.2 SE

The notation for the 99 percent confidence limits (assuming normality) and/or the 90 percent confidence limits (if normality is not assumed) of the stochastic distribution of the average STOCEM results exhibited.

3. MODELS, ROUTINES, AND SIMULATIONS

ATCAL	Attrition Model Using Calibrated Parameters - generates simulated combat attrition results, suitable for use in a theater-level simulation
CEM IX	Concepts Evaluation Model IX - a two-sided, fully automated, deterministic model capable of aggregating conventional warfare results as a series of 4-day theater-level cycles
COSAGE	Combat Sample Generator - a two-sided, stochastic, high-resolution (division-level) simulation model which simulates a day's combat activity to generate ammunition consumption and equipment and personnel loss data
STOCEM	Stochastic Concepts Evaluation Model - a stochastic version of CEM VII, a two-sided, fully automated model capable of aggregating conventional warfare results as a series of 4-day theater-level cycles

4. DEFINITIONS

casualty rate
[number of casualties]/[number of onhand personnel] over all personnel in the line units available for commitment in the ARCAS scenario.

casualty types
The mutually exclusive casualty subcategories defined as KIA, WIA, CMIA, and DNBI.

D-day
16 December 1944, which is the starting date of the STOCEM scenario of the Ardennes campaign.

mechanized weapon
A weapon system in the APC or AT/M class modeled in STOCEM.

permanent casualties
Those personnel casualties, in the line units available for commitment in the ARCAS scenario, which never return to duty during campaign. All KIA and CMIA are considered permanent casualties.

reference point(s)
One of a set of geographic point locations of a subelement of a military unit recorded in the Unit Location Data Base subset of the ACSDB.